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The cover is a micrograph of the structure of a large steel forging, photographed with green filter at the laboratory of The Midvale Co. The layout and the water color of a 75-ton forging are by Elizabeth Dwyer.

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The Revolution in Steel

THIS PAPER IS WRITTEN to summarize the results on the steel industry of the governmental policies since 1932, as well as the war and postwar pressure for high production, at higher and higher costs in every department. New processes are being carefully considered, as well as new adaptations and combinations of old processes, which will indeed result in revolutionary advances in production rates of every unit and especially those units concerned with the production of ingots. If labor costs per unit are abnormally high, then the production per man-hour must be increased. If the cost of raw materials is excessive, then means must be found to use less or cheaper materials per unit produced.

An industry as large and as basic as the steel industry must plan for decades ahead, yet there is no really good method for foretelling the production trends and economic developments of even a few years in advance. This, in addition to the shrinkage in the purchasing value of financial reserves and the extreme uncertainty as to the cost and availability of labor, raw materials and power in the years just ahead, make the problem of providing a sound program one of extreme intricacy and difficulty. Every executive knows that there is an end eventually coming to the present producer's market, and that good old-fashioned competition for markets will once more make the sales department and quality of product the most important factors in the business volume. When this change comes, any argument that the steel industry is a monopoly will fade into thin air in the bitter fight for markets. Production per unit per man-hour will be even more important than it is now, with the accent on low operating costs rather than high tonnage totals.

To develop the highest production rates per unit per man-hour is one study, and the combination of these high production units into the best possible producing plant is another study. The best layout and location of this plant to fit best into the steel production and marketing picture for 25 years ahead is still another study.

Degree of integration is a difficult problem to solve. Judging by performance from 1925 to 1940, the "semi-integrated" plant melting its own steel seems to offer the best return on investment (with the "nonintegrated" plant a bad third). The "fully integrated" plant is handicapped during periods of low production because of the difficulty of making pig iron to compete with low-priced scrap, and the high cost of operating large continuous mills on small and varied orders.

During the years from 1925 to 1930 the nonintegrated steel plant found little difficulty in getting enough semifinished re-rolling billet and sheet bar tonnage to keep going at a good rate — primarily because of the relatively higher price at which the semifinished product sold as compared to the finished product. From 1930 on, the picture changed; sale of re-rolling billets and sheet bar became very unattractive to the integrated steel producer. One factor in this change was the introduction of detailed cost accounting which brought to light many items that were being sold at little or no profit.

Large producers therefore attempted to with-

By Harry W. McQuaid
Consultant
Cleveland, Ohio

draw from the semifinished market, the nonintegrated plant was forced to think about making its own steel, and the result was a sharp increase in the number of plants which put in steel-melting facilities. Ever since the "blue eagle" days the building of openhearth and converter plants was restricted by code, so this concentrated attention on the electric furnace for the production of common grades of carbon steel. The economic success of these installations has been demonstrated by Connors Steel Co., Northwestern Steel and Wire Co., Joslyn Mfg. Co., Texas Steel Co., and others. Undoubtedly this trend will continue.

Consumer-Owned Steel Plants

Large *consumers* of steel will also think seriously of producing their own requirements of steel to avoid future shortages and shutdowns. The extremely successful operation of such consumer-owned units as those of International Harvester Co. and Timken Roller Bearing Co. proves such combinations can be logical and financially sound.

Whether a large steel user should install his own steelmaking facilities is a question which in a way is parallel to the one which has led many large users of castings to put in their own foundries. Even relatively small producers of large forgings made in hydraulic presses have seen fit to install steel-melting equipment. One of the important factors in the economics of the steel plant operated by a steel user is the daily tonnage required and the type of finished product. If electric furnace units are carefully selected, they can shut down and start up with little difficulty and the melt shop operation can be adjusted to suit the forge or rolling mills. On the other hand, continuous operation of the openhearth is desirable, and running only one or two furnaces is costly. It is evident, therefore, that with a standard setup of openhearth and blooming mill, the minimum tonnage for economical operation is high, and the investment likewise is high.

Much of the thinking as to the consumer operating his own steel plant will probably be based on the use of modern high-voltage, high-powered electric furnaces, casting ingots designed for minimum conversion and conditioning. This type of installation will produce relatively small monthly tonnages of all grades of steel at an interesting cost and a maximum of operating flexibility. Cheaper production of carbon steels in the electric furnace, and the use of special ingot practice for direct rolling in a single conversion into the final rolling mill product, would fit well into the program of almost any large consumer of either carbon or alloy products.

Blast Furnace Economics

The present basis of large tonnage steel production is the basic openhearth. It, in turn, is dependent on the blast furnace and the scrap market. The blast furnace is dependent primarily on coal, air and ore, with limestone as an important but secondary base material. Thus we can say that the modern basic openhearth is dependent primarily on coal, ore and scrap. Before the war the price of scrap was consistently below that of iron, so the openhearth operator pressed for more scrap and less iron. However, even with cheap, high-quality scrap, 60% hot metal (iron) was found to be economical in many plants. Under these circumstances, iron was then the most important factor in openhearth costs; it is much more so today, with poor quality scrap costing a high premium over iron. Therefore the demand is now stronger for iron than ever before. But iron requires coke, and more costly coal has resulted in a most important increase in cost of coke. Thus, the reward for an increase in iron production per unit of coke is greatly increased.

The problem of increased blast furnace production has been approached through increased blast pressure and the use of oxygen. These programs, either singly or in combination, seem to have merit and the 2000-ton blast furnace, at coke rates well under what now seems excellent, is promised for 1948.

At first this big production of iron will probably be used directly in the openhearth, but eventually most or all of it will probably be processed through the converter and then finished in the large openhearth (or, in some cases, the electric furnace). This is not at all a new procedure, but today's economics indicate that it is most logical.

Thus, in the next five or ten years, we may see big, fully integrated plants built around large openhearth furnaces supplied (by special converters) with a medium carbon, low-manganese, low-silicon, all-hot-metal charge. The coke ovens, bessemer and openhearth units will be closely coordinated to obtain finished steel at the maximum rate from the openhearths. Production rates up to 50 tons per hr. will be common. Such practice will require high scrap additions to the blast furnace and bessemer. The amount of coke oven byproducts and blast furnace slag will increase with the over-all efficiency. Need for purchased scrap will not only diminish, but there should be a considerable amount of high-grade heavy melting scrap, available as surplus, for sale.

The present tight scrap situation will stimulate greatly the trend to the type of operation just described. High labor costs under present meth-

ods of operation and relatively low production rates will also be an important factor. Having already been in operation for many years, there is little except the normal objections of the financial departments to prevent adoption by the large, fully integrated plants. One of the early operations of this type was at the Illinois Steel Works at South Chicago, more than 30 years ago, where blown metal from the converter was held in a large tilting openhearth which supplied two 15-ton electric furnaces making alloy steel.

Role of the Converter

Operation of blast furnace, converter and openhearth in combination, such as at present by Jones & Laughlin Steel Corp. and the U. S. Steel Corp.'s Alabama plant, is dependent on large supporting coal, coke and blast furnace facilities. The investment required is enormous, but for the largest scale, most economical ingot production it is well warranted, in the opinion of some steel producers. Why should it now become more interesting than in the past? One answer is in the greater need for more tons per man-hour from the openhearth, and another is the uncertainty of future scrap prices. Likewise, much more low-carbon, semikilled and rimmed steel is going into flat rolled products, and the availability of oxygen for rapidly driving the bath to a very low carbon makes the use of the converter between the blast furnace and the openhearth more attractive. These grades of steel with their high yield, ingot to shipment, do not return very much discard as scrap for normal openhearth operations. The openhearth is fundamentally a poor means of reducing carbon, since the reaction with ore is endothermic and requires much time and extra fuel. On the other hand, the modern converter is ideal for carbon reduction. By leaving to the openhearth only the duty of reducing phosphorus and adjusting final carbon and temperature, high quality steel can be made three to four times as fast as a rate now considered good.

The converter practice will be determined by the blast furnace product and the openhearth requirements. The aim is the economical production of the final ingot. There is no doubt that, by using the converter simply to remove carbon to approximately the point which best suits maximum openhearth production, a large increase in ingot production can be obtained with minimum fuel. Caustic treatment of the molten iron to reduce sulphur and the usual openhearth practice give a product which would be highly satisfactory to meet tonnage steel quality requirements.

Whether side-blown or bottom-blown converters will be used is difficult to say. It is the writer's opinion that when full carbon removal is not desired, an improved type of side-blown converter will be preferable, because of its better control, especially if oxygen supplements the air in the lower carbon blow. Oxygen is also a means of heating the metal so hot that scrap is added to keep the temperature down to that desired for best results in pouring. Such additions of scrap are highly economical.

In its logical development, the side-blown vessel will resemble a small tilting openhearth, perhaps without a roof, and perhaps with facilities for adding ore, air, oxygen and scrap. Ore might be an initial addition to oxidize the excess silicon, phosphorus and manganese, and air and oxygen depended upon to remove the carbon. Many such operating variations are possible, but the fact that silicon, phosphorus and manganese oxidize fastest at the lower temperatures, and carbon oxidizes fastest at the higher temperatures, makes temperature control and timing of oxidation agents the most important factor. It is also possible that the roof could be off the furnace during the blowing period, yet replaced after adding scrap and during the finishing period. At any rate, most thought centers around the production of the most economical ingot with little or no interference by a shortage in scrap.

One of the problems involved in large-scale converter operation and use of oxygen in openhearths is that of fumes. A project such as just discussed would lead to much objection from the surrounding community if located in an urban area. The control or elimination of fumes will be part of the urgent problems of the steel plant engineer in the near future but, in view of the success of nonferrous smelters in handling the far more serious and toxic fumes of sulphur, lead and arsenic, will undoubtedly be satisfactorily solved.

If such a program spreads throughout the steel industry, it will be necessary to increase blast furnace capacity and install converters, but the number of openhearths will, of course, be reduced, since the production per furnace will be at least tripled. Since this process will require no outside scrap (and even might become an important *source* of scrap), its effect on the economics of openhearth and electric furnace operations will be of great importance.

Its effect on plant *location* will probably be minor. It will increase greatly the ore requirements of some of the larger plants, most of which now have their own coal and ore properties. The amount of ore required per ton of steel will be greater than with the present operation without the converter, but the improved economy in the

openhearth will probably overcome any effect this might have on ore prices. The cost of the iron in ore being as it is, its use to replace melted scrap in the openhearth will more than pay its cost to the blast furnace and the converter, unless scrap prices drop lower than seems probable.

This operation, as visualized, will reduce greatly the steel mill's fuel requirement for melting, but will increase the amount of coal per ton of ingots required as coke, due to the heavy iron charges to steel refining units. Just what this will be (with the use of oxygen and high pressure on the blast furnace) remains to be seen.

Metallurgical Oxygen

The use of oxygen has been the most discussed topic of the year by steel mill operators. It will undoubtedly prove a widely used and valuable tool in melting cold charges in present-day openhearths, just as it has in conditioning of hot iron and in scrap preparation. It promises an important improvement in blast furnace and converter output. Its use in the refining stages of steelmaking will, for the near future, probably be confined to the carbon reaction.

The availability of high-purity, lower cost oxygen, from generators in the mill, will spread its use for cutting, scarfing and for carbon reduction in making very low-carbon steel, as well as in the melt shop for increasing bath temperature and for cleaning banks. These oxygen generators are reliable and simple to operate, and have an economic appeal in that they work on a raw material which is free and everywhere. The larger tonnage generators are similar in principle to the equipment for making high-purity oxygen, but use less power per ton of oxygen because they operate at a much lower pressure. One is now being installed at Weirton Steel Co. to make 400 tons of oxygen per day for blast furnace use.

High Tonnage Electrics

The electric furnace, except in a few applications, has been thought of as a high-cost means of making high-priced, completely deoxidized steels. As a matter of fact, it is much more than that. If power is available, it promises to supplant all but the largest openhearth furnaces as the source of *any* grade of steel. This is especially true in the semi-integrated plants, but its replacement of the openhearth even in a semi-integrated plant will depend primarily on the cost and availability of pig iron, scrap and power. In the past, a good grade of heavy melting scrap was usually cheaper than pig iron. This day may return again, but if it does, it will be due to the greatly increased use of the converter for preparing the openhearth (or electric furnace) charge.

As a matter of fact, the *large* electric may be highly competitive with the openhearth as a means for finishing hot, partially decarburized iron from the converter. This is because the operation of an electric furnace *for the same grade of product* is usually more economical than an openhearth, except for power and electrode costs, which in turn are directly related to the energy required for the actual melting of the all-scrap charge. If a liquid charge is available, already close to temperature, the higher speed and efficiency of the electric furnace cut the costs of power and electrodes by 80% of an all-scrap charge.

The inherent advantage of the electric over the openhearth for high tonnage operation is not so much one of low oxidizing melting as it is one of higher temperature. This idea may be contrary to much that has been published, but where the power is available *and used to the practical limit*, it is possible to melt scrap at almost any desired speed and to heat it 100 or 200° F. hotter than the usual working temperature in the openhearth.

This is indeed a great advantage since it permits higher lime slags, higher oxide bath and slag content, and much faster carbon removal. The net result is that the electric furnace can be, and is, a much better working tool than the openhearth for making low-carbon heats, high in iron oxide. Thus, for semikilled and rimmed low-carbon grades, the well-powered electric produces better and faster heats than an openhearth four times its capacity! The high iron oxide is an important factor in the yield and surface quality of semikilled steels, especially in small ingots.

Top-charged furnaces with high voltage and power input can charge and melt scrap at an amazing rate. For example, Northwestern Steel & Wire Co.'s plant, using 40,000 amperes at 350 volts, is making semikilled steel in 32-ton heats at a rate that compares more than favorably with many 200-ton openhearths. A photograph of this furnace is reproduced on page 93. Of course, the management has concentrated on getting the most from an electric furnace. It is also a tribute to graphite electrodes capable of putting energy into steel scrap safely and surely at such a rate.

Such work seems to demonstrate that there is apparently no limit to the rate at which scrap can be melted in an electric furnace if the voltage is high enough and the power is available. It is not too much to expect that voltages as high as 440 will be common, and the amperage governed by the size of the charge and current-demand limitations. It will possibly halt the growth in size

of large electric furnace units to the one which gives the fastest melting with the largest transformer and electrode commercially available. The 24-in. graphite electrode and the 25,000-kw. transformer are about as large as seem practical for the next few years. Using secondary voltage of 400 and with perhaps 50,000 amperes, it should be possible to melt 50-ton heats in close to 1 hr. This, with a well designed, top-charged furnace, would result in well over 20 tons per hr. of semikilled steel, which means that one such furnace could turn out close to 15,000 tons of ingots per month.

Electric furnaces of the past were designed for alloy steels and much slower operation. For high production of carbon steels, where every minute is precious, they will have to be redesigned for heavier electrodes, much faster operation of electrode motors, and rapid roof swing. Redesign of top-charging equipment is also necessary.

An important factor in the competition of electric furnace with openhearth is that of availability of power. While a $5,000,000,000 building program is underway in the power industry, large blocks of new power will hardly be available before 1949 — much of it not until years later.

It is probable, however, that many semi-integrated steel producers now using openhearth melting furnaces will find power available and will make the change. Until the openhearth can operate at the higher temperatures necessary for faster melting and finishing, the electric furnace will be a better method of making all grades of steel, especially when using a cold charge and relatively small furnaces. Openhearth refractories may be improved for higher temperature operation; work is already being done in this direction.

Billet-Type Ingots

When a 20-ton electric furnace can outproduce a 100-ton openhearth on semikilled and rimmed steel from cold charges, it looks attractive to the large steel consumer who is thinking of making his own steel. Combined with billet-type ingots, light-gage final products can be made by a single conversion from the small ingot, at a cost comparing favorably with that of the fully integrated plant using large ingots which require several conversions. An excellent example of this can be seen at the Connors Steel Co. in Birmingham, Ala., where hoop stock and cotton bail ties are rolled directly from the ingot in a well-worked-out mill. Such ingots are also adapted to produce hot breakdowns for hand sheet mills, or wire rod.

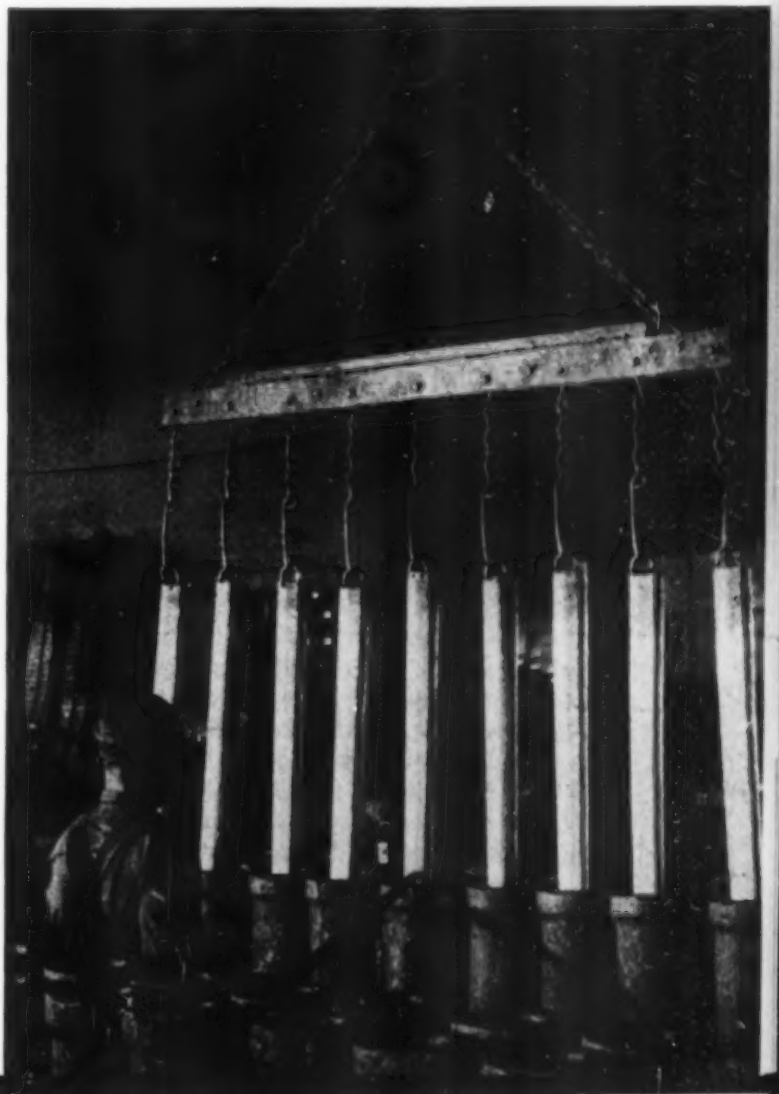
The advantage of the billet-type ingot is that its rate of freezing is so fast it is inherently free from harmful segregation and it is unusually sound. It is cast with the big end up, and the ratio of mold weight to ingot weight is about five times that of the large ingot designed for a blooming mill. The writer has seen and made many tests of the internal structure of Connors' ingots and it is obvious that here is a means of reducing conversion and conditioning costs to the very minimum. Mold life, by the way, is six or seven times that of a conventional ingot mold.

In spite of its obvious advantages in a small plant the billet-type ingot has been little considered by the large mills because it is difficult to fit into a large continuous operation. For the smaller plant of the semi-integrated type, it offers interesting savings and high yields in small finished product which are hard to meet by the largest fully integrated producers.

Thermochemistry of Steelmaking

For years the metallurgical thinking in America, as it concerns melting, has been an inheritance from the practices used in England, Sweden and Germany. Some place much stress, in making so-called quality steels, on pure mate-

Stripping Billet-Type Ingots at Connors Steel Co., Birmingham



rial in the charge, long time under low oxide slags; overheating was considered fatal to quality. (At one time an aluminum addition was considered fatal to quality steels, but now it is specified on practically every heat of alloy and quality carbon steel by metallurgists some of whom have never seen molten steel!)

Now a new picture is showing itself. Oxidation is beginning to be looked upon favorably and deliberately encouraged as a necessary step in the making of clean steel as free as possible from hydrogen. It is beginning to appear that, for the highest quality steel, it is necessary to have a good action in the bath — an action caused by the combination of iron oxide in solution in the bath with carbon, also in the bath. American melters — and also metallurgists — are beginning to understand more clearly the effect of temperature on the relative oxidation rates of carbon, silicon, manganese and phosphorus. Thus, there is an obvious advantage of ore or scale in the charge to take care of silicon, phosphorus and manganese because of their greater oxidation rates at the lowest bath temperature. While this is a generally accepted tenet of openhearth practice, it is just being realized by the electric furnace operators. Furthermore, the advantage of carbon as a deoxidizer at high temperature (over 2950° F.) is just beginning to be accepted.

Some of the leading metallurgists are beginning to realize that a completely deoxidized steel is not necessarily the best steel, and that in many instances a long hold under deoxidizing slags may be detrimental to good quality because of the hydrogen and nitrogen picked up. As Clarence E. Sims puts it: "The evidence keeps piling up, as we gather experience, that vigorous action and a strong oxidation condition during the refining of the heat are very necessary for the best quality of steel." This is far from crucible steelmaking, where you got out what you put in, and only a dead melted heat of the highest purity charge could give high quality steel. It means that openhearth practice with a high carbon meltdown and an active boil is essentially the best, providing the temperature and deoxidation practice are correct for the type of product desired.

In the electric furnace it means that a good working meltdown and a so-called "single slag practice" will increase in favor because of the lower hydrogen and nitrogen in the heat. If the second slag is used (of a high-lime, low-oxide type) it will only be to adjust temperature and analysis. In this coming change in electric furnace practice, accurate pyrometers for measuring bath temperature are necessary, since temperature is the basic governing factor in bath fluidity and the rate of oxidation of unwanted elements. Temperature also is a prime factor in slag reactions and slag fluidity, and hence its control is most important for quality steel.

Excellent immersion-type pyrometers have

Immersion Thermocouple, Developed by Republic Steel Corp., Canton Plant

recently been developed. Bath temperatures can be accurately determined even to a considerable depth. This puts an entirely new control into the melter's hand; properly used it avoids cold taps, which were the primary causes of many heats which would not pass metallurgical inspection. Likewise, temperature control is all-important in working out the fastest, most economical melting practice.

Effect of Aluminum in Steel

Two of the most important papers* which will affect the thinking and practice in steel metallurgy are those of Sims and Dahle describing the effect of aluminum on the properties of medium carbon cast steel, and of Low and Gensamer on aging and yield point in steel.

Aluminum added to steel has a well-known influence on grain growth and associated physical properties. Sims and Dahle showed that this depended on a critical combination of aluminum and sulphur which formed in the as-cast grain boundaries, and that the effect of this envelope constituent was greatly increased by an increase in nitrogen. This finding was of the greatest importance to steel castings — likewise to rolled and forged products requiring high transverse properties. The aluminous constituent is a primary cause of banding and boundary carbide coalescence, and apparently reduces the solubility of carbon in the metal bordering the grain boundaries. It is obvious that the old story which so many metallurgists believed, that aluminum oxide was the sole cause of resistance to grain growth, is very much of a myth.

The effect of the aluminum-sulphur-nitrogen combination on the grain boundary stability of carbides has been of especial importance when low-alloy and carbon steels are subjected to high temperatures for a long time. Here the tendency of graphite formation in the fine-grain, aluminum-treated steels has caused some important failures.

It is also an important cause of hot shortness in forgings and castings, low ductility in steel castings, and of early ferrite precipitation in the grain boundaries of as-quenched structures. These three results of a single addition indicate that the study of chemistry as it affects the as-cast microstructure is of great importance, and must include the combination effects of minute quantities of such elements as boron, titanium, vanadium and columbium, in addition to aluminum and the more usual elements such as phosphorus, sulphur, nitrogen and chromium. Certainly interest will grow in the physical metallurgy and metallog-

*"Effect of Aluminum on the Properties of Medium Carbon Cast Steel", by C. E. Sims and F. B. Dahle. American Foundrymen's Assoc., Preprint No. 38-22, 1938.

"Aging and the Yield Point in Steel", by J. R. Low, Jr., and M. Gensamer. *Metals Technology*, December 1943 (Technical Publication No. 1644, A.I.M.E.).

FORM K 101-8-03-1000.

THE ADVANTAGES OF THE USE
OF
ALUMINUM IN STEEL.

THE USE OF ALUMINUM IN STEEL HAS BEEN CONTINUALLY GROWING, UNTIL NOW ALUMINUM IS VERY LARGELY USED IN BESSEMER STEEL AND IS ALMOST UNIVERSALLY USED FOR OPEN-HEARTH STEEL AND CRUCIBLE STEEL.

THE USE OF ALUMINUM INSURES A PERFECT BILLET BY REMOVING THE OCCLUDED OXYGEN AND OTHER GASES, AND BY REDUCING THE CARBON OXIDE AND CARBON DIOXIDE WHICH IS IN SOLUTION OR SUSPENSION IN THE STEEL; THUS PREVENTING BOTH THE FORMATION OF BLOW-HOLES IN THE INGOT AND THE CHURNING AND CONSEQUENT OXIDATION OF THE STEEL BY THE EBULLITION OF THE GASES.

STEEL, TO WHICH A SMALL PERCENTAGE OF ALUMINUM HAS BEEN ADDED, SOLIDIFIES VERY QUICKLY AND THUS PREVENTS SEGREGATION OF IMPURITIES AND GIVES BETTER CRYSTALLINE STRUCTURE. THE QUICK COOLING AND THE STOPPING OF THE EBULLITION OF GASES RESULTS IN A SOLID AND SQUARE END ON THE INGOT. THE CROP-END ON THE ROLLED PLATE THEREFORE IS VERY SMALL AS COMPARED WITH THAT PRODUCED BY THE ORDINARY METHOD, AND THIS SAVING ITSELF PAYS FOR THE COST OF THE ALUMINUM.

ALUMINUM DISSOLVES VERY QUICKLY IN STEEL AND MIXES RAPIDLY AND UNIFORMLY, AND SUCH SMALL QUANTITIES ARE REQUIRED THAT ITS INTRODUCTION DOES NOT LOWER THE TEMPERATURE. SO SMALL A QUANTITY IS REQUIRED THAT THE COST OF THE ALUMINUM DOES NOT ADD MATERIALLY TO THE COST OF THE STEEL.

WE FURNISH FOR USE IN STEEL EITHER FIRST QUALITY ALUMINUM, GUARANTEED OVER 99 PER CENT PURE BUT AVERAGING ABOUT 99½ PER CENT ALUMINUM, OR A SECOND GRADE OF 98 PER CENT ALUMINUM. THE IMPURITIES CONTAINED IN ALUMINUM CONSIST OF IRON AND SILICON, NEITHER OF WHICH ARE DETRIMENTAL TO IRON OR STEEL.

THE PITTSBURGH REDUCTION COMPANY.
PITTSBURGH, PA.

A 1903 Leaf Promoting a New Idea

raphy of the as-cast intercrystalline precipitates and their effect on the characteristics of carbide.

Low and Gensamer showed that the removal of all but mere traces of carbon (and nitrogen) resulted in an iron without any definite elastic limit (yield). This would indicate that a prime contributing factor in the elastic limit phenomenon was carbide. The practical duplication of these results without loss of carbon by adding critical additions of aluminum indicated that plastic yield depended more on the form in which the carbide existed than on its quantity as indicated by analysis. Low-carbon sheet steel, free from pearlite, lost most of the elastic range after a critical addition of aluminum, and the microscope showed that this loss was accompanied by the presence of coalesced carbides, generally at the junction of three ferrite grains. Thus it might be argued that the yield point is associated with steels having continuous boundary carbide films; this can be present even in steel with carbon below 0.05%. The usual elastic limit would represent the load that could be carried by this carbide (and nitride) film until it failed.

It might be speculated that the final continuous precipitation of carbides in the boundaries of the low-carbon or carbon-free grains is the factor which determines the true elastic limit, and it is the rupture of this carbide and nitride boundary phase which results in a change from a true elastic reaction of the boundary carbide to a plastic reaction of the ferrous grain. Thus, as long as the applied stress is distributed entirely by the envelope carbide (or nitride), we say the reaction to the loading is within the elastic range, and when this intergranular envelope is ruptured, we say we have exceeded the elastic limit, since the ferrite grain acts as a plastic body.

It might be reasoned that the final carbide film exists only between ferrite grains. Any such film in a low-carbon steel surrounding or between pearlitic grains would imply a condition existing in a true hypereutectoid steel. This is quite debatable. While a fine carbide film may be present even between pearlitic grains, the resistance to distortion by the whole carbide structure would be strengthened by a boundary (envelope) carbide.

This suggestion of a final precipitated carbide film is contrary to the widely held idea that the final fractional per cent of carbon is not in the envelope as a carbide, but in solution in the ferrite. What gives the idea of a carbide envelope some standing is that a little aluminum in very low-carbon steel causes the appearance in the grain boundaries of coalesced carbides (and nitrides), and these have an important effect in reducing the elastic limit to a very low value.

There is also a real possibility that the almost universal use of aluminum in steel for grain-size control may be changed in the near future. Tests made on openhearth and electric furnace grades of carbon steel in bar form have shown that aluminum, as usually added, is very detrimental to machinability. This is apparently due to abrasion by aluminum oxide and silicate inclusions on the cutting edge of the tool. These inclusions are formed in large quantities in steel to which aluminum and silicon are added in the deoxidizing process. Their number is increased greatly by exposure to the air during pouring.

Since machinability is a more and more important item in production costs, the pressure for low-silicon, aluminum-free steel for machined parts becomes greater. For screw machine parts and other similar applications, aluminum may be discarded and some other metal such as vanadium substituted in spite of the higher alloy cost. In the automotive and farm implement field this idea may even be applied to many alloy steels.

Hardenability Specifications

Another trend which promises to react unfavorably on the openhearth melter is the trend to hardenability specifications, especially by the operator of continuous heat treating furnaces of large capacity. Thus we seem to be heading for the day when the general chemistry will be specified, *plus* a range in hardenability, as indicated by the Jominy or similar test, and which is governed by the results to be obtained on a continuous heat treating furnace. When this day comes, openhearth alloy steel melting will quite definitely be more difficult.

To what degree this change will affect a given openhearth shop will depend on the state of the steel market, the "toughness" of the buyer, and the condition of his heat treating equipment. A close hardenability range is much more difficult to guarantee than most heat treaters believe. While chemistry as such is the most important factor, there is not a straight line relation; various combinations of elements have different effects, as have ingot size, deoxidation methods, and pouring practice and temperature. The position of the test piece in relation to the ingot section or to the whole heat is also a definite factor.

After all, the openhearth melter has only chemistry as his direct aim, and much work remains to be done to insure meeting the narrow hardenability ranges which are just around the corner. It looks as if hardenability, like grain size, will be a big factor in improving the demand for steel mill contact metallurgists.

A schedule of "Metallurgical Milestones Witnessed by the ⚙" gradually expanded into a major project. It is presented by the Editor with that humility desirable in all efforts to be concise, inclusive and accurate

Metallurgy in America, 1917-1947

1917

"Rezistals" (high chromium-nickel-silicon alloys) formulated to resist cutting flame by Charles M. Johnson of Crucible Steel Co. of America.

Metallic heating (and melting) by **high-frequency induction** currents invented by Edwin F. Northrup at Princeton University.

First ingots cast from **electric furnaces** at South works, Illinois Steel Co., Chicago.

Powder method of crystal analysis by **X-ray diffraction** invented by A. Hull.

C. H. Mathewson and Arthur Phillips published a systematic study of **recrystallization** of alpha brass.

Automatic, **continuous heat treating furnace** (capacity 3 tons per hr.) built by Electric Furnace Co. Temperature of work controlled by Bristol equipment.

1918

Alloy iron castings heat treated and installed as tractor parts by Holt Mfg. Co.

"Paper" electrode (cellulose covering) for arc welding patented by R. S. Smith and O. E. Andrus.

Handy & Harman installed **high-frequency furnace** (to melt 175-lb. charges of silver) made by Ajax Electrothermic Corp.

Directional magnetic properties of single crystals of silicon-iron determined by W. E. Ruder of G. E. Co.

Molybdenite concentrates shipped from Climax, Colo.

International Nickel Co. replaces fire **refining of nickel** ores at Bayonne, N. J., with electrolytic process in new refinery at Port Colborne, Ont.

Plant for manufacturing **aluminum powder** constructed at Logans Ferry, Pa., for Aluminum Co. of America.

Automatic pyrometric control with potentiometer pyrometer introduced by Leeds & Northrup Co.

1919

J. M. Camp and C. B. Francis' **"The Making, Shaping and Treating of Steel"** published.

Silcrome valve steel produced to P. A. E. Armstrong's patents at Watervliet plant of Ludlum Steel Co.

P. D. Merica, R. G. Waltenburg, Howard Scott and J. R. Freeman, at National Bureau of Standards, discover the **mechanism of age hardening** in duralumin.

First successful production of **magnesium by electrolysis** of brine by Dow Chemical Co.

A. Hull demonstrates, by X-ray diffraction methods, the body-centered cubic **lattice of alpha iron.**

Triple-alloy, air hardening **die steel** (Ni-Cr-Mo) devised by Wm. Finkl.

Aluminum Research Laboratory established at New Kensington, Pa., Francis C. Frary in charge.

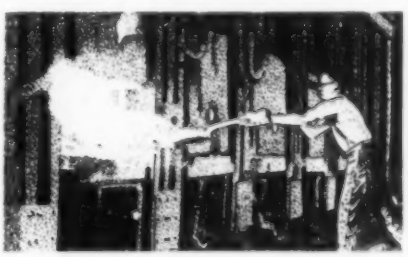
1920

Danforth **venturi port** developed and installed on an openhearth furnace at South works, Illinois Steel Co.

First national convention of **American Society for Steel Treating** (Philadelphia).

Manufacture of **hardness tester,** invented by S. P. Rockwell, started by Wilson-Maeulen Co.

Synthetic molding sands resulted from studies at Cornell University sponsored by American Foundrymen's Assoc.



1921

McQuaid-Ehn test for "abnormal" and "normal" carburizing steels devised.

High magnetic permeability induced by heat treatment in iron-nickel **"permalloy"** by Gustaf Elmen.

Autofrettage (self-hooping by cold working) of large gun tubes at Watertown Arsenal.

First **alloy cast steel rolls** made for rolling mills; molybdenum also used in chilled iron rolls.

Forging alloys of aluminum formulated by R. S. Archer and Zay Jeffries at Aluminum Castings Co. (Cleveland). Aluminum-silicon alloy castings also appeared.

Electrolytic refining, to purify commercial aluminum, developed by Wm. Hoopes.

Union Carbide & Carbon Research Laboratories organized under direction of Frederick M. Becket.

1922

Steckel mill with take-up and hold-back reels produced cold rolled shim stock on commercial basis.

W. R. Chapin proves experimentally the existence of **martensite transformation point** in steels at temperatures around 300° F.

Electro-Motive Co. organized for manufacturing gasoline-electric driven railcars.

Slip interference theory of hardening proposed by Zay Jeffries and R. S. Archer.

Radiography used as a method for steel foundry control (H. H. Lester at Watertown Arsenal).

Rolling mill for **nickel and its alloys** started operations at Huntington, W. Va. Development and Research Division of International Nickel Co. organized; A. J. Wadhams, manager.

Desulphurization of molten iron with soda ash initiated in America at Griffin Wheel Co.'s foundry in Chicago by George S. Evans.

1923

Continuous hot sheet mill (58-in.) built at Ashland, Ky., plant of American Rolling Mill Co. by John B. Tytus.

Babcock & Wilcox Tube Co. pierced billets of 28% **chromium-iron** for Cutler Steel Co.

Grain size control put into practice (50 heats of "coarse-grained normal" carbon-chromium steel for roller bearings) by Central Steel Co. of Massillon, Ohio.

N. B. Pilling and R. E. Bedworth propose general law for **scaling rate of metals.**

"Superlattices" discovered in solid solutions by E. C. Bain.

Ground shafting produced by Cumberland Ground Steel Co.

Oilless **porous bronze bushings** ("Durex") devised by Harry M. Williams and A. L. Boegehold.

1924

Timken Roller Bearing Co. produced rotary pierced and spheroidized Cr-C **steel tubes for bearing races.**

First Naismith **sloping back-wall** installed in an openhearth furnace (South works, Illinois Steel Co.).

"Metals Handbook" made its appearance in the form of 808 loose-leaves.

Zay Jeffries and R. S. Archer's **"Science of Metals"** published.

1925

Copper-silicon binary alloys for corrosion resistant structural and mechanical members patented by Charles B. Jacobs.

First meeting of **Openhearth Steel Committee** of the A.I.M.E.

Batch-type furnace with **circulating gas atmosphere** built by Leeds & Northrup for the Greenfield Tap & Die Co.

Magnesium die castings made.

Gun tubes made by **centrifugal casting** at Watertown Arsenal (T. C. Dickson).

Study of **high-temperature properties** of metals started at University of Michigan (C. L. Clark for Detroit Edison Co.).

"Konel" (age hardenable Ni-Co-Fe-Ti alloy), predecessor of "K-42-B" and other high temperature alloys, developed by P. H. Brace and I. F. Lowry of the Westinghouse Research Laboratories.

Nonfuming bronze **welding rod** devised by A. R. Lytle (Oxweld Acetylene Co.).

1926

First steel melted commercially by **high-frequency** currents from motor-generator sets by Babcock & Wilcox Tube Co.

High chromium-iron stainless alloys made by **direct reduction of chromium ore** with ferrosilicon at Rustless Iron Corp. of America in Baltimore.

18-8 (0.09% C) made by Allegheny Steel Co.

Cooperative investigation into the **physical chemistry of steelmaking** started at Bureau of Mines station in Pittsburgh.

Atomic hydrogen welding devised by Irving Langmuir and R. A. Weinman of General Electric Co.

Manufacture of cutting tools of **cemented tungsten carbide** started in Schenectady by General Electric.

Contacts and electrodes made of powdered W or Mo plus Cu or Ag by P. R. Mallory & Co.

F. F. Lucas constructed an **ultraviolet** optical system for microscopy.

Emery hydraulic capsule and Bourdon-tube load indicator applied to **physical testing machines** by Baldwin-Southwark, Philadelphia.

W. P. Sykes discovered **age hardening** in carbon-free iron alloys (Fe-W and Fe-Mo).

1927

Alclad aluminum alloy sheet developed by Edgar H. Dix, Jr., of Alcoa's research laboratories.

First installation of 4 to 6% **Cr steel tubes** (pressure stills at Port Arthur refinery of The Texas Co.).

Electron diffraction methods applied to metallic surface phenomena by G. Davisson and L. H. Germer.

The German nitriding steels (Cr-Al-Mo) produced as **"Nitralloy"** by Ludlum Steel Co.

"Ni-hard" roll for four-high continuous hot strip mills made by Mackintosh-Hemphill Co.

U. S. Steel Corp. organizes **central research** laboratory (Kearny, N. J.), John Johnston at its head.

Chromium-molybdenum air-hardening steel (tungsten free) for **die casting dies** developed by Climax Molybdenum Co. under direction of Norman I. Stotz and C. H. Herty, Jr.

Soderberg type of **aluminum reduction pots** installed in Alcoa, Tenn., plant of Aluminum Co. of America.

Flame hardening of rail ends to resist wheel batter applied to mainline trackage. Westinghouse's Nuttall Works used process for hardening gear teeth.

1928

Seamless tubes of 18-8 Cr-Ni stainless steel applied extensively in petroleum stills by Humble Oil & Refining Co. (Steel made by Central Alloy Steel Corp., tubes pierced by Babcock & Wilcox Tube Co.)

Mechanical twins in iron, zinc and copper analyzed by C. H. Mathewson of Yale University.

Frood mine opened by **International Nickel Co.** at Sudbury, Ont.

Controlled atmosphere furnace, to minimize scale on steel bars, furnished Timken Roller Bearing Co. by Electric Furnace Co.

Hard-faced oil well drilling bits prepared by welding-on tungsten carbide, by H. W. Fletcher.

Elmer A. Sperry devised electrical instrument for **inspecting rail** for soundness while test car is traveling over the track.

1929

Production of **99.99% zinc** (electrolytic) started by Sullivan Mining Co. and used for die castings by Doehler Die Casting Co.

Shielded arc (coated electrode) placed on sale by Lincoln Electric Co.

Battelle Memorial Institute opened its doors in Columbus, Ohio.

White metal **strip bearings** first produced by Cleveland Graphite Bronze Co.

Hardened alloyed iron became commercial (used for diesel cylinder liners by Caterpillar Tractor Co.).

Vertical retort (continuous) for **zinc smelting** perfected by New Jersey Zinc Co.

Shot-peened springs (then called "shotblasted") shipped by Barnes-Gibson-Raymond of Detroit.

W. L. Fink and E. D. Campbell demonstrated that **martensite** has a body-centered tetragonal structure.

A. M. Byers Co. starts commercial production of wrought iron by **James Aston's process** at Ambridge.

"Magnaflux" test for tiny surface defects developed by A. V. deForest.

All-welded gun carriage of nickel steel made at Watertown Arsenal.

Nitriding furnace (convection type) built by Leeds & Northrup Co. for Cadillac Motor Car Co.

C. C. Nitchie, working at N. J. Zinc Co.'s research laboratory, perfected **spectrographic method of analysis** employing impregnated electrodes.

Wheeling Steel Corp. (Yorkville, Ohio, plant) produced cold reduced steel sheet in tin-mill widths and gages for subsequent manufacture of **tin-plate.**

Rails investigation, directed by H. F. Moore, started at University of Illinois, sponsored by Chicago Elevated Railroads (since 1931 by American Railway Engineering Assoc. and technical committee of Rail Steel Manufacturers).

Alloys of Fe, Ni and Co with thermal expansion equal to glass (Kovar) devised by Howard Scott of Westinghouse Research Laboratories.

1930

Production of **flash-welded pipe** in 40-ft. lengths begun by A. O. Smith.

J. D. Edwards, F. C. Frary and Zay Jeffries published **"The Aluminum Industry".**

"Metal Progress" and **"Metals Review"** started publication.

Alloys of Iron Research of Engineering Foundation started activities.

E. S. Davenport and E. C. Bain describe their studies on **isothermal transformation** (S-curves).

Cemented **tantalum carbide** introduced as a tool material by Fansteel Metallurgical Corp.

St. Joseph Lead Co. commenced production of zinc oxide in **electrothermic shaft furnace.**

Radium (gamma rays) used for metal examination by R. F. Mehl, G. E. Doan and C. S. Barrett at U. S. Naval Research Laboratory.

Commercial **pressure die casting** of copper base alloys (brass).

Manufacture and heat treatment of **molybdenum high speed** toolsteel (Mo-Cr-V-C) worked out by S. B. Ritchie at Watertown Arsenal.

Submerged arc welding discovered by Rubinoff. Shielding by inert gas (argon or helium) patented.

Sodium replaced salt for cooling of **hollow valves** for high-duty gas engines (Thompson Products, Inc.).

Refined iron (99.95%) commercialized by Westinghouse Electric & Mfg. Co., using methods of melting and annealing in vacuum devised by T. D. Yensen in systematic work dating back to 1914.

1931

Grain refining of **magnesium castings,** by superheating the melt, patented.

Diescher mill for finishing pierced rounds started operating at Babcock & Wilcox Tube Co.

Continuous **gas carburizing** started in Chrysler Corp.'s Newcastle plant (Surface Combustion equipment).

Rails welded end to end in mainline trackage (Delaware & Hudson Ry.)

Equipment for **continuous bright annealing** of steel and nonferrous strip and wire made by Process Engineering & Equipment Corp., Attleboro, Mass. (Bright annealing of copper tubes in Chase Brass & Copper Co.'s Euclid, Ohio, plant in 1932.)

I. C. Mackie introduces **slow cooling of rails** at Dominion Steel & Coal Corp., Sydney, Nova Scotia, to avoid shatter cracks leading to internal transverse fissures.

Intermediate Cr-Mo steels for high temperature processes marketed by Timken Steel & Tubes.

1932

A. J. Castle at Indiana Harbor works devised a rough shotblasted surface on **rolls for cold mills.**

Oxygen-free, high-conductivity **copper** first offered by U. S. Metals Refining Co.

Tungsten-molybdenum **high speed steel** perfected by J. V. Emmons.

Principles of age hardening applied to carbon-free **permanent magnet alloys** by R. S. Dean, S. K. Seljesater and B. A. Rogers.

Gas generator for scale-free annealing of brass cups and shells built for Remington Arms by Electric Furnace Co.

Production line for **steel belt links** for machine gun ammunition established at Rock Island Arsenal.

Timken Roller Bearing Co. placed **graphitic toolsteels** (invention of F. R. Bonte) in production.

1933

"The Book of Stainless Steels" published by ASM.

Society name changed to **American Society for Metals.**

Silicon and phosphorus limitations placed on steel base of **tin-plate** to insure resistance to most corrosive food products (American Can Co.).

First meeting of **Electric Metal Makers Guild** (Palmer House, Chicago).

1934

Edward G. Budd Mfg. Co. builds and Burlington Lines puts **"Pioneer Zephyr",** the first of the high speed passenger trains, in operation between Lincoln and Kansas City.

Copper-lead **steel-backed** bearing strip made by **continuous casting** (Cleveland Graphite Bronze Co.).

B. F. Shepherd developed penetration-fracture test for **hardenability of toolsteels.**

"Alnico" (Al-Ni-Co-Fe) alloys for permanent magnets patented by W. E. Ruder of General Electric Co.

Tellurium-lead (hard alloy) produced from British patented process by National Lead Co.

Spectroscope used for foundry control at Watertown Arsenal.

Radiant tube heater elements in annealing furnace built for Superior Sheet Steel Co. by Lee Wilson.

Free-cutting aluminum alloys developed by L. W. Kempf and W. A. Dean of Aluminum Co. of America.

Crystals of **high-purity silicon** used for detection of microwaves (Bell Telephone Laboratories).

Carbon control of axle shafts during hardening by adjusting H_2O and CO_2 to steel's carbon content (W. H. Holcroft's furnace in Dodge automotive plant).

1935

Free-cutting copper alloys containing tellurium developed by D. E. Lawson.

Electronic circuits added to thermoelectric millivoltmeter for indicating (later recording and control) devices by Wheelco Instruments Co.

First **induction hardening** unit sold for commercial use (by Ohio Crankshaft Co. to International Harvester's Tractor Works in Chicago).

Chromium-aluminum-iron (37.5-7.5-55.0) alloy for **electrical resisters** described by S. L. Hoyt and M. A. Scheil.

Commercial production of **silicon-iron transformer sheet** with oriented crystals by Allegheny Steel Co., using process of N. P. Goss.

Composite roll ("Ni-hard" body and soft iron necks) for sheet mill work rolls invented by H. E. Walters of United Engineering & Foundry Co.

Age hardenable nickel-copper-aluminum alloy **(K Monel),** developed by W. A. Mudge and P. D. Merica, and marketed by the International Nickel Co.

Precipitation hardened copper-chromium alloys for **resistance welding electrodes** (P. R. Mallory & Co.).

Casings for very deep oil wells made by **cold compression** of welded tubes (T. M. Jasper at A. O. Smith Corp.).

Cast armor plate made by Lebanon Steel Foundry to Watertown Arsenal's specification (used extensively on medium tank M3 for U. S. Army, starting in 1940).

Direct chill ingot casting for aluminum alloys commercialized by W. T. Ennor of Aluminum Co. of America.

1936

Continuous casting process for copper billets, American Smelting & Refining Co.

First **diesel-electric locomotive** from LaGrange shop, Electro-Motive Division, General Motors Corp.

Accelerated "hydrogen evolution" test for predicting corrosion resistance of coated **tin-plate** adopted by steel producers.

Internal standards method for quantitative spectrographic analysis successfully applied at Campbell, Wyant and Cannon foundry, Muskegon, Mich.

Austenal Laboratories (N. Y.) adapted **lost-wax process** for casting dental and surgical items to larger industrial castings, close to size.

Fatigue machines for testing full-sized mechanical parts installed at Timken (Canton) laboratory under O. J. Horger's direction.

1937

Immersion-type radiation pyrometer for measuring **temperatures of molten steel** made by Leeds & Northrup Co.

Telephone receiver improved by diaphragm of ductile iron-cobalt-vanadium alloy (Bell Telephone Laboratories).

5-1-1 Cr-Mo-C air hardening **tool and die steel** produced by Braeburn Alloy Steel Corp. (developed by Howard Scott and N. I. Stotz).

Chromium-copper alloy ("Cupaloy") with high wear resistance and electrical conductivity, devised by P. H. Brace and commercialized by Westinghouse.

W. E. Jominy and A. L. Boegehold propose **end-quench test** piece to measure hardenability.

1938

Lead added to steel to improve **machinability** by C. E. Sims, J. W. Halley and J. H. Nead.

Fourth (revised) edition of D. K. Bullens' **"Steel and Its Heat Treatment"** published.

First commercial heat of **boron-treated steels** made at Wisconsin Steel Works.

R. S. Burns, H. F. Moore and R. S. Archer demonstrate that the hardness of fully-quenched **martensitic steel** depends upon its carbon content only.

M. A. Grossmann, Morris Asimow and S. F. Urban analyze, quantitatively, **the quenching operation.**

W. A. Anderson and R. F. Mehl present complete analysis of **recrystallization** in terms of allied metallic properties.

Silver bearings (lead-indium) produced for Pratt & Whitney aircraft engines.

Pressure welding of steel parts, heated below melting point by gas flames (Union Carbide & Carbon Research Laboratories).

Atmosphere generator utilizing **endothermic reaction of gas** in catalytic mass installed by Ingersoll-Rand Co. (based on work by John R. Gier and C. E. Peck at Westinghouse Research Laboratory dating back to 1929).

Stress-rupture test for high temperature service described by A. E. White, C. L. Clark and R. L. Wilson.

Oxygen used to blow carbon out of electric furnace heat of stainless steel by E. J. Chelius (South works, Carnegie-Illinois Steel Corp.).

1939

E. C. Bain's **"Functions of the Alloying Elements in Steel"** published by American Society for Metals.

President Roosevelt appoints "Advisory Committee on Uranium", and the hunt for an **atomic explosive** is on in earnest.

First unit for **drying blast furnace wind** put in operation at Woodward Iron Co., Birmingham, Ala.

Hardened armor plate successfully welded with austenitic electrodes (specification by Bureau of Construction & Repair, U. S. Navy).

1940

1,000,000-volt **X-ray unit** installed in works laboratory of General Electric Co. at Schenectady.

First **electron photomicrographs** of steel structures made by R. F. Mehl in Zworykin's laboratory, working with E. G. Ramberg and R. F. Baker.

High-alloy, oil quenched **drive gears** replaced by medium carbon steel gears, induction hardened, by Caterpillar Tractor Co.

First electrical resistance **strain gages** bought by Douglas Aircraft Co. (made by A. C. Ruge of Massachusetts Institute of Technology for Baldwin-Southwark).

Cemented tungsten carbide cores used for armor-piercing **projectiles.**

Brazing of aluminum alloys commercialized by G. O. Hoglund and M. A. Miller of Aluminum Co. of America.

Production of **aluminum** begun on Pacific Coast at Vancouver, Wash.

Age hardenable **stainless steel** (18-8 type) developed by R. Smith and E. H. Wyche in Wood works laboratory, Carnegie-Illinois Steel Corp.

1941

Process for recovery of **magnesium from sea water** perfected by Dow Chemical Co.

Work on **"National Emergency" steels** (NE8000 to 8500) started by H. LeRoy Whitney (War Production Board) and John Mitchell of Carnegie-Illinois Steel Corp.

A. B. Greninger and A. R. Troiano devised accurate methods of determining temperature of **martensite** formation.

Magnesium reduced by **L. M. Pidgeon's ferrosilicon processes** in wartime plants.

High-temperature alloy "16-25-6" (Cr-Ni-Mo) developed at Timken Roller Bearing Co., under leadership of Martin Fleischmann.

Steel cartridge cases successfully cold drawn from flat disk by Corcoran-Brown Lamp Division of Electric Auto-Lite Co. in Cincinnati and by Norris Stamping & Mfg. Co. in Los Angeles. (3-in. shells for 50-caliber naval guns put into production by latter firm in 1942.)

1942

Field gun barrels made from seamless tubing (Timken Roller Bearing Co.).

First trials of **oxygen** to speed-up openhearth melt-down and refining periods (Hamilton plant, Steel Co. of Canada).

Machinability of heat treatable openhearth steels improved by additions of sodium sulphite.

Crucible melting of steel abandoned in U. S. (last heat at LaBelle works, Crucible Steel Co. of America, Pittsburgh).

Electrolytic tin-plate for food packing adopted as a tin conservation measure by the canning industry.

1943

Electric Furnace Steel Committee organized by A.I.M.E.

Automatic, autographic **creep testing machine** devised by M. J. Manjoine.

Lime-sinter adjunct to Bayer process for recovery of **alumina from silicates** devised by Ralph W. Brown and installed at Aluminum Ore Co. (East St. Louis).

Weldability of steels systematically defined in relation to hardening near the weld by W. F. Hess and in relation to notch-bend ductility by G. E. Doan.

First experimental airplane (Chance Vought Aircraft) with structure designed around **"sandwich" construction** — low-density core, metal faced.

1944

Publication of **"Basic Openhearth Steelmaking"**, by A.I.M.E.

Supersonic inspection equipment developed for subsurface surveying.

S-816 (20:20:43 Cr:Ni:Co) high-temperature heat resisting alloy produced by Allegheny Ludlum Steel Corp.

1945

Uranium bomb devastates Hiroshima and plutonium bomb Nagasaki.

Addition of potassium nitrate to **phosphor bronze** melts for pressure-tight castings (Naval Gun Factory).

Heat treated nickel-chromium-molybdenum steels (135,000 psi. min.) for **naval gun components.**

Heat resistant alloys in chromium-molybdenum-iron system developed at Climax Molybdenum Co. laboratories.

1946

Vacuum melting and casting of large bodies of **ductile molybdenum** perfected by R. M. Parke at Climax Molybdenum Co. laboratories.

Periodic reverse current proposed, to deplate any inferior **electrodeposits** while building increments of sound metal.

In any evaluation of an existing situation it is essential to consider related facts. In appraising the technology of metallurgy and metal treatment, it is more than ever necessary to consider the underlying and bordering sciences, as does Dr. Condon in his broad discussion

Science and the National Welfare*

SOCIETY is at this moment at the threshold of an undreamed of mastery of our material environment, for Science, which provides that mastery, is in its Golden Age.

In particular, achievements in nuclear physics promise incredible advances in the years ahead. Energy from atomic power plants has been much talked about, but even more important are the tools provided by nuclear physics for research in other fields. Radioactive isotopes, for example, will permit us to explore the structures and constitution of molecular aggregates, for such isotopes can be introduced into a system as scientific detectives. They will behave as the usual atoms of the particular element behave, but they can be traced and studied by means of the radiation they emit, and unravel secrets in biology, physiology, medicine, chemistry, and metallurgy.

The combined effect of tracer studies, of a variety of sources of radiation, of various sources of high intensity, highly-accelerated subatomic particles, and of fundamental knowledge of the nucleus will result in spectacular advances in many fields. The problem of curing fatal diseases will be successfully attacked; fundamental biological and physiological processes will be understood; new types of therapy will be developed in medicine; better control of intricate chemical manufacturing processes will be feasible; new products, like petroleum fuels and metals with unusual properties, will be possible; and even new forms of plant life can be created. The speed with which these possibilities are realized depends primarily on how much effort we put into such activities. For there is no question that the impetus of the new knowledge in nuclear physics, in conjunction with steady advances in other fields of science during the last 50 years, means a general efflorescence of the physical and life sciences.

But if we are to profit from this happy situation, there are major problems to be solved, and their solution will not wait. From one point of view, life today is a race — a race between knowledge in the physical sciences which gives material mastery, and general ignorance which retards or rejects mastery of our environment. Rejection means no more and no less than destruction of civilization as we know and cherish it.

Problems of Science — The problems confronting us, approaching them from the standpoint of the sciences, exist on several planes. Two, in particular, are the specific problems of science as science, and the question of these sciences in relation to the other activities of man. The problems arising within the sciences themselves are extremely practical ones, and on the whole they are not complex.

Several axioms are at once apparent. First, science is universal. Second, science is unlimited in its material. Third, the rate of scientific progress depends on the amount of effort put into science.

*Extracts from an address delivered before a meeting of the American Council of Commercial Laboratories held in Washington, December 8, 1947.

By E. U. Condon
Director
National Bureau of Standards
Washington

Photo by Mildred Ferguson

These axioms are important. They mean that no individual or no nation has a monopoly in science, that science affords an inexhaustible mine of valuable knowledge and discoveries, and that we must be willing to support science appreciably if we expect to gain heavily and to maintain leadership.

A comprehensive and cogent analysis of the problems of science is to be found in John R. Steelman's recent report to the President, "Science and Public Policy". While his main recommendations are eight in number, I would like to discuss one of them briefly.

It is recommended that expenditures for research and development be expanded as rapidly as facilities and trained man power can be provided. A suggested goal is that, by 1957, 1% of the national income should be expended in research and development in universities, industry, and government laboratories. A little over 1.1 billions are being spent this year for research and development, excluding the social sciences. With a national income of 200 billion, this is an expenditure of little more than 0.5%. Only about 110 millions, or less than one tenth of the total, is spent for basic research. Almost half enters into the development of military weapons and needs, not including the amount spent for atomic bomb development (now considered to be a civilian activity). Dr. Steelman therefore recommends that support for basic research be provided for the Federal Government at a progressively increasing rate, reaching an annual rate of 250 millions by 1957, with double that rate as an eventual goal. This proposal leaves ample scope for large-scale and expanding support of basic research by private groups and state governments.

One of the great difficulties about a major program of expenditures on basic research is that it is so difficult to explain to an appropriations committee from a national or state legislature — and even to management in private business — what the program will accomplish. It is necessary to entrust funds for research programs on faith, on the competence of the leaders of such programs; furthermore, this trust must be maintained for a sustained period of time. It is characteristic of most fundamental research that several years are required for the completion of any work of importance and that the effects may be difficult to evaluate by anyone.

What, for example, is the cash value of Einstein's discovery of the relation, $E = mc^2$? No doubt it is an astronomically large value now. But what was its worth at the time of its formulation? And who was qualified to make the evaluation? The point simply is this: Pure knowledge cannot be evaluated in cold cash, and pure knowledge is independent of such evaluations. Unfortunately, appreciation of this fact is not as widespread as it should be.

One of the dangers facing us in the present situation is overconfidence. The United States has led the world in technological progressiveness and in the techniques of mass production. We are, without question, the most powerful nation in the world. In these very facts lies the essential danger, for overconfidence is a product of precisely this set of circumstances. Illustrations of pride preceding fall fill the pages of history, and civilization after civilization has perished in this fashion. We need glance backward no further than the recent war to see Germany, a once scientifically sophisticated power, lose leadership and initiative.

For many years, during the latter half of the 19th Century and the early 20th, science in Germany was in a position of international prominence, and yet we now know how misguided and superficial were their efforts in the direction of atomic energy. I believe that two factors were at play here: First, the Nazi leaders eliminated the truly first-rate scientific leaders and installed second-rate party-men in positions of scientific leadership. Second, there are obvious evidences of overconfidence in the scientists as well as the nation in their scientific ability and achievement.

Thus, after the revelation of our work in atomic energy, we had the spectacle of, first, the

German refusal to believe that accomplishment, and second, childish attempts to pretend that they had not wanted to develop an atomic bomb but that they really had progressed in atomic research and that their researches were to be devoted to peacetime uses. These rationalizations would be merely amusing were they not also sardonic.

The obvious lessons of the past, as far as science is concerned, indicate that competent leadership must be fostered in science, and that we must never take for granted future achievements on the basis of past performances. This thought leads to another danger confronting us: As a nation we have been outstanding in *applying* science; we have not been outstanding in basic scientific *discoveries* or theory. If we are to attain our goals, it is imperative that basic research be supported on a large scale.

In atomic energy, for example, we were essentially dependent upon the work of European scientists for our basic knowledge, and European scientists in this country contributed heavily to our success, in particular Fermi and Szilard. Again, during the first half of the war, we were dependent on British research and development in radar for our own program, and it was not until the latter portion of the war that we contributed in a basic way to this field. Then our contributions, particularly in microwaves, were significant.

Essential Research

A comprehensive and broad program of research in the field of synthetic rubber is a matter of national wisdom, and similar programs are needed in other fields, many of them not of such vital concern on the surface. For example, a national program of basic research on optical glass is a primary desideratum, and yet the thought of the importance of optical glass is not likely to occur to those not engaged directly in military problems because the annual requirements of this country for precision optical instruments for civilian purposes during a period of peace are almost negligible when compared with the demands made upon our industry by our military agencies during war. If we are to be again prepared for future eventualities, a program of research and experimentation must be maintained.

Stockpiling of optical glasses is not a solution, for stockpiles tend to maintain the status quo, saddling the military services with obsolete instruments and making the introduction of better glasses and instruments difficult. As a general rule (with valid exceptions only in the case of basic raw materials) stockpiling is futile, for it tends to hinder progress.

Science and Man's Safety

Even these few illustrations indicate that science does not function in a vacuum. It is a preeminently practical thing, dealing with crucial problems affecting industry, business, the nation, and the world. It costs money and it demands the efforts not only of scientists but every segment of our population. Too often science is pictured as an "ivory tower"; on the contrary, it is concerned immediately with our industrial economy, it operates within the full context of social existence, and it deals with practical problems as much if not more than with theoretical ones. One of the discouraging attitudes widely prevalent in the contemporary world is the high regard placed upon what is called "practical" and the low esteem granted the "theoretical". In point of fact, the two differ only in *time;* fundamental knowledge merely precedes applied knowledge.

The operations and progress of science can therefore be understood fully only in terms of the framework of our general society and in relation to the other activities of man. This context is particularly significant when we consider that science has now placed in our hands tools that are equally potent for good or evil. I have been talking, for the most part, about the good, but actually the potential evil is more important.

Of what value is this growing potential of good if science is used to destroy the civilization from which it has sprung?

It is fashionable to cry down the so-called pessimist who suggests this dangerous possibility, because man is largely a hopeful creature with a belief that at worst he will muddle through, and largely because the dangers are difficult to group and appraise as a consequence of the staggering difference in kind and degree of present dangers in the form of scientific warfare. It is sufficient to say for my purposes that science has presented us with *several* weapons each of which unleashed can mean almost total, if not total, destruction.

The question then is how to prevent such a situation. The answer is not to be found in the physical sciences. It is to be found in other realms of man's activity — in economics, in sociology, and in political science. Man's conduct in the physical sciences is rational; in these other fields of the humane sciences it is largely arbitrary.

It is often said that man's social irrationality is a consequence of the fact that economics, sociology, and political science are not sciences, that they are merely individual judgments and personal opinions. Now this is palpably untrue even at present, for much is known about cause and effect in these fields, and such statements are made only

because habit, custom, tradition and heritage tend to make us cling to whatever we know, rather than to re-examine the data, coolly and critically.

Admittedly, these humane sciences are younger than the physical sciences. Moreover, the variables to be accounted for are vastly more numerous than those we deal with in the physical sciences. But these are not adequate reasons for belittling the humane sciences and denying them support; on the contrary, these are compelling reasons for supporting them, and the present state of civilization demands that they receive this support. As a matter of fact, since the physical sciences have outstripped man's capacity for using them wisely, sanely, religiously, it is of the utmost urgency that we attempt to forge ahead in the humane sciences, lest all be lost. Furthermore, this is the time for intensified activity in these fields, not only because of the urgency of our need but because now the physical sciences have two tremendous tools to contribute to the humane sciences, tools that will permit scientific analysis of data having a large number of variables.

Statistics and Computers

The first of these tools is statistics which provides the theoretical, mathematical basis for analysis, the mathematical techniques for handling data, and the criteria for evaluating results. Mathematical statistics is now a substantial and well-developed discipline, and it does, in fact, offer these tools. Second is the possession of automatic electronic computing machines, on which many laboratories and companies are at work. These machines handle and analyze data, rapidly and comprehensively. One of the major problems in fields where vast amounts of data are obtained has always been the handling and classifying of the data. Literally thousands of man-days are needed in even relatively simple problems. This means that research is expensive, and the humane sciences have not been able to afford such luxuries.

As an example of the labor involved, consider a relatively simple census problem involving 100,000 pairs of five-digit numbers, representing statistical data. It takes approximately 12 working days to get the answer, exclusive of card handling and data punching. An electronic digital machine will handle the same sequence in 10 min.!

Just as there is a disparity in the evaluation of research between the physical and the humane sciences, so too there appears to be an analogous disparity in the attitude of most people toward research between the medical and the mental sciences. Like the physical sciences, the medical sciences produce what are called tangible results — new drugs, new clinical techniques. Like the humane sciences, the mental sciences do not appear to produce materialistic results, and have suffered similarly in the support granted them for research.

This, too, is a situation that needs remedy. Psychology, psychiatry, and psychoanalysis are disciplines pertinent in the solution of current problems. Aside from the statistical fact that three out of every seven beds in the hospitals of the United States are occupied by the mentally ill — a vast drain in terms of lost man power and cost — and that untold numbers of borderline cases permeate the entire social structure, we need to know more about the workings of the mind. For there is little doubt but that nonevident factors like frustrations and fears affect human behavior profoundly.

These factors affect every activity of man, his personal, social, political, and even scientific life. From the standpoint of science, we can say not only that science affects individuals and nations, but that these individuals and nations affect science. Even from this restricted approach, then, what has happened or happens to men's minds and spirits is of interest if we have scientific objectives in view. We have seen how entire nations have apparently succumbed to a schizophrenia that has led to the espousing of mad, undemocratic, bestial beliefs. We have seen at least one nation despoil its scientists as a result of such an aberration.

Compartmentalization in the sciences and in other fields is inimical to a coordinated attack on the problems of man. This compartmentalization is actually breaking down in the sciences. The distinction between chemistry and physics, for example, has almost vanished. Competent research in the social sciences now depends on mastery of mathematics, and on the utilization of the electronic tools. The complexity of modern life depends on specialization for progress in particular fields but, for over-all progress and for a solution to the dilemma of unbalances, integration and coordination are essential. In short, education of a comprehensive nature, embracing many fields, is needed for the survival of our civilization.

The sciences, like those other truth-seeking activities of man, require a free environment, an environment above all free of fear, petty arbitrariness, and tyranny. The pursuit of the sciences is fundamentally nothing more — or less — than the pursuit of truths. Yet in the last analysis, all of man's activities are subservient to what happens to his spirit — to his spiritual welfare. "For what shall it profit a man, if he shall gain the whole world, and lose his own soul?"

Spheroidization, but no graphitization, was observed during exposure at 1000 to 1300° F. over time periods up to 5000 hr. for normalized specimens of 0.14% carbon, 0.53% molybdenum steel of fine-grain deoxidation practice

Spheroidization of Molybdenum Steel in High Temperature Service

FOR A NUMBER OF YEARS, molybdenum steel has been used in steam boilers, oil cracking stills, and other equipment operating at high temperature and pressure. Considerable information has been accumulated concerning the original properties of this material in various conditions, but less is known about how it changes during service. Microstructural changes, such as spheroidization and graphitization, which may occur during service at elevated temperature, alter the properties, and may be expected to weaken the metal, at least as measured by comparative room-temperature tests. Examination of parts removed from service might be expected to yield valuable information regarding these changes, but too often the true service conditions are unknown or were varied in an ill-defined way; moreover, the specific properties of the original material are usually unknown, rendering any valid conclusions difficult or impossible.

The literature relating to structural changes in this and other steels during exposure at elevated temperature has recently been reviewed by G. V. Smith, R. F. Miller and C. O. Tarr in a paper printed in the 1945 *Proceedings* of the American Society for Testing Materials ("Structural Changes in Carbon and Molybdenum Steels During Prolonged Heating at 900 to 1100° F., as Affected by Deoxidation Practice"). The present contribution, which is in the nature of a supplement to this earlier work, presents in chart form a series of photomicrographs illustrating the change of microstructure and hardness in a normalized 0.14% carbon, 0.53% molybdenum steel, of so-called fine-grain deoxidation practice, when held at 1000, 1100, 1200, or 1300° F. for an extended time. The changes which occurred were spheroidization and precipitation of what is believed to be an iron-molybdenum-carbon compound. This compound has already been described in the paper cited above and in another in *Transactions* for 1938, p. 817, by R. F. Miller, R. F. Campbell, R. H. Aborn and E. C. Wright: "Influence of Heat Treatment on Creep of Carbon-Molybdenum and Chromium-Molybdenum-Silicon Steel."

The marked effect of temperature upon the spheroidization behavior is readily apparent either by inspection of the photomicrographs on the next two pages or from the small graph, Fig. 1. No graphitization was observed in these samples, in

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The work described was done by the authors at the U. S. Steel Corp.'s Research Laboratories, Kearny, N. J. Mr. Miller is now with Carnegie-Illinois Steel Corp. in Pittsburgh, and Mr. Golaszewski is now a student at Purdue University.

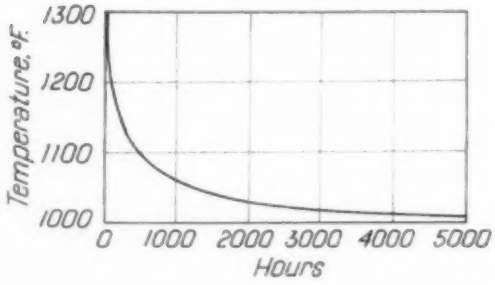
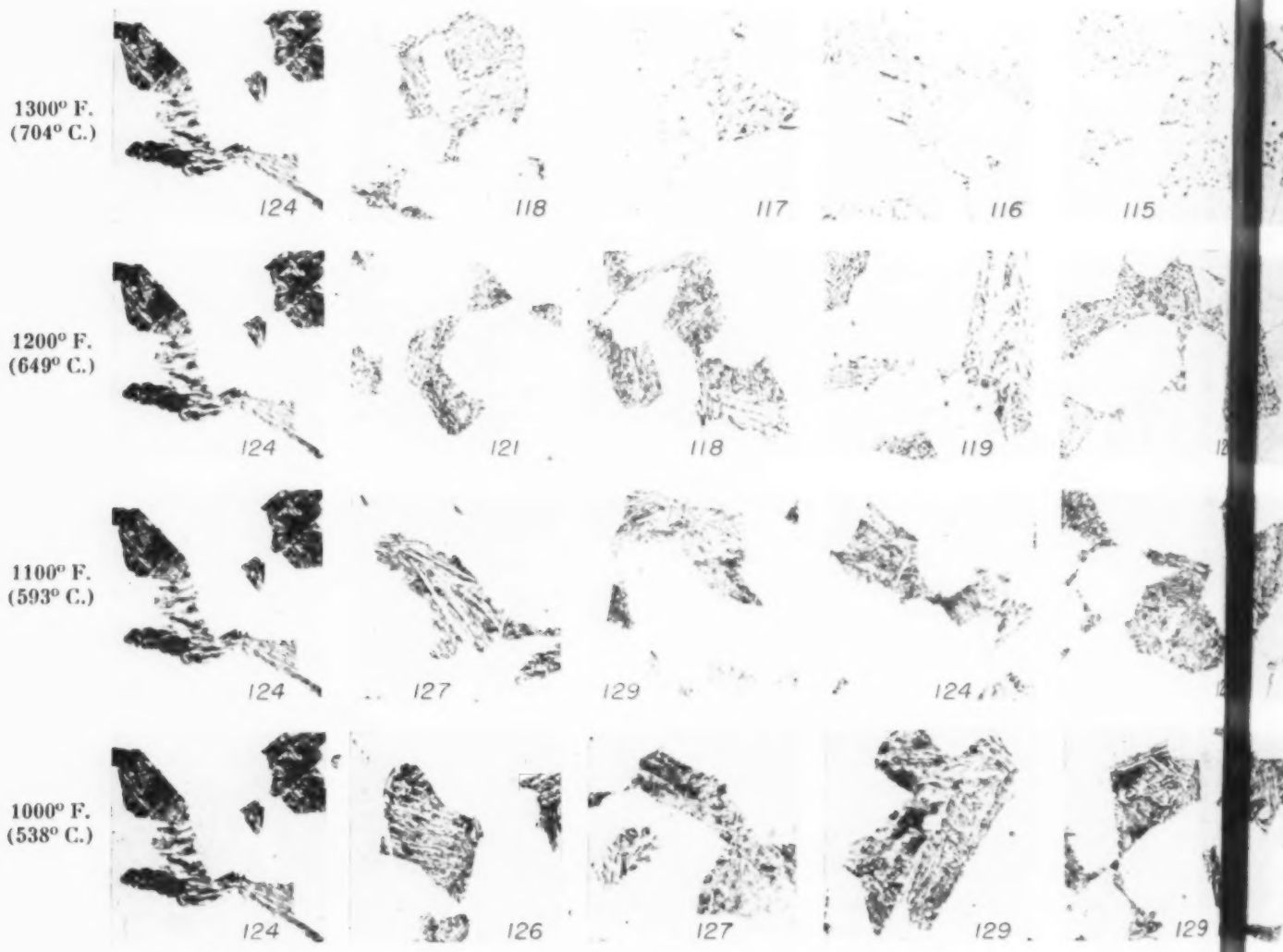


Fig. 1 — Approximate Time Required for Detectable Spheroidization of Pearlite in a Normalized 0.14% C, 0.53% Mo Steel as a Function of Temperature

spite of the use of fine-grain deoxidation practice in the manufacture of the steel. The decrease in hardness was not pronounced at any temperature, apparently owing to the moderating effect of some precipitation process on the normal softening which accompanies spheroidization.

The steel chosen for study was from a commercial heat, supplied by National Tube Co., of the following composition: 0.14% C, 0.55% Mn, 0.016% P, 0.023% S, 0.15% Si, 0.53% Mo, 0.020% Al, and 0.026% Al_2O_3. It had been deoxidized according to so-called fine-grain practice, involving the addition of silicon and about 1.5 lb. aluminum per ton of steel. (This is in contrast with the coarse-grain deoxidation now generally practiced for steels for high temperature, in which the aluminum addition is limited to 0.5 lb. or less. It will be recalled that grain coarsening increases creep resistance measurably; also — as pointed out by Albert E. White in his article on "Graphitization of Steels at Elevated Temperatures" in September *Metal Progress* — aluminum deoxidation accelerates the reaction of carbide to graphite.)

In order to establish a uniform original structure, the starting condition was that produced by normalizing 30 min. at 1650° F. The resulting



Effect of Time at Temperature on Microstructure of Normalized Molybdenum Steel. 500×

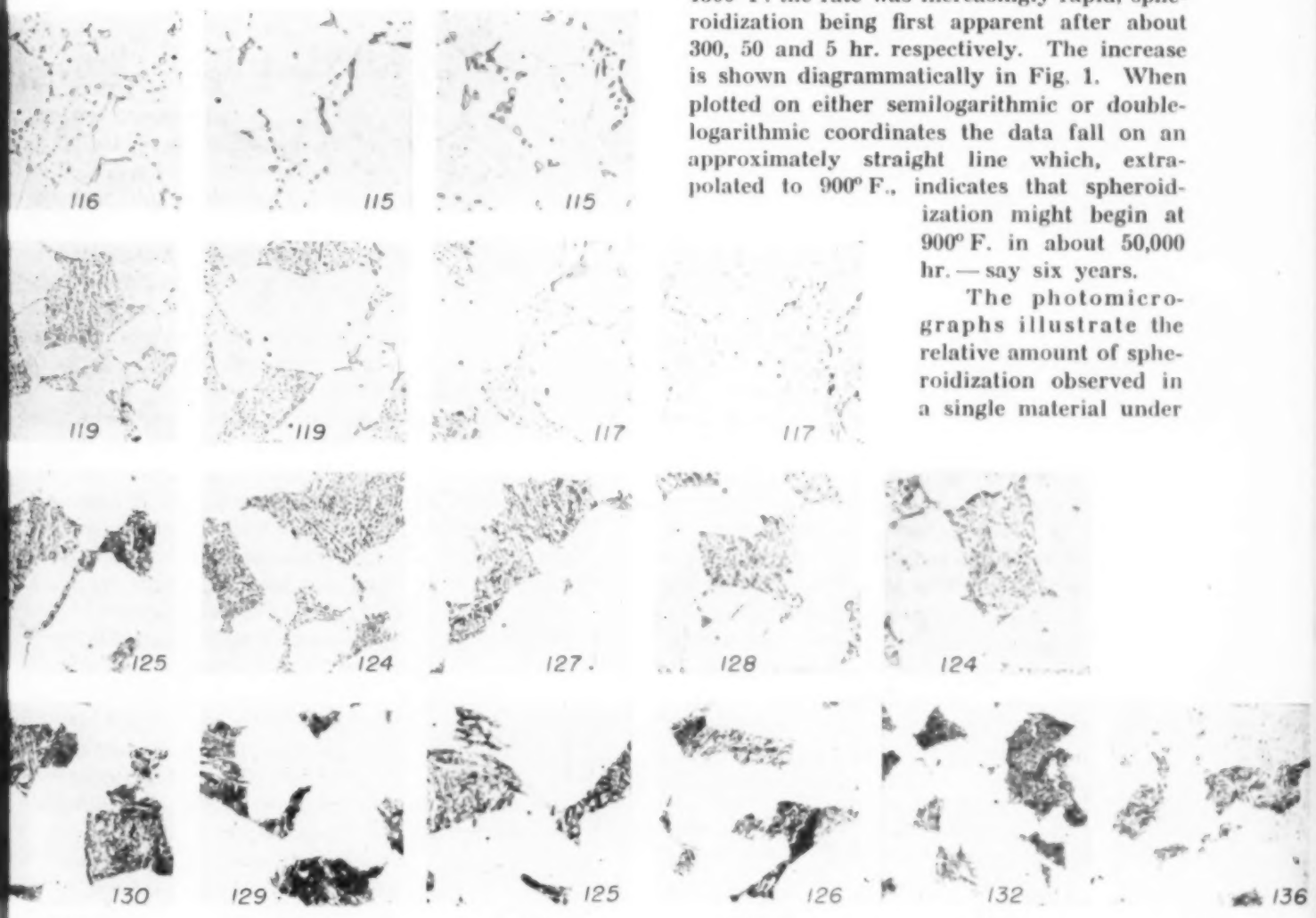
microstructure consisted of ferrite and a rather irregular pearlite characteristic of molybdenum-bearing steel. Series of specimens were then held in molten lead, periodically deoxidized, for various intervals up to 5000 hr. at 1000, 1100, 1200, or 1300° F. After exposure, each sample was sectioned and examined metallographically, and its Vickers hardness determined.

The resulting microstructure and hardness are shown as a series for each temperature in the accompanying micrographs below. For comparison, the micro at the right end of the 1100° F. row has been reproduced in Fig. 2, page 86, alongside one representing a sample of 0.5% molybdenum steel, of unknown deoxidation practice, which had been removed from an oil cracking still after about 30,000 hr. (3.5 years) at a temperature reported to be about 1100° F. The changes clearly indicated in our control sample — spheroidization of lamellar carbide and its accumulation at grain boundaries — have been carried much further in the steel of the oil still, exposed to high temperatures ten times as long as the laboratory test.

With increasing time at temperature the carbide of the pearlite gradually spheroidizes and migrates to the grain boundaries, and a fine precipitate of what is probably a complex iron-molybdenum-carbon compound appears throughout the matrix. The slight, but apparently real, increase in hardness accompanying spheroidization of the pearlite at 1000 and 1100° F. is presumably caused by this precipitation, which has been found to increase creep strength under certain conditions. See, for example, the work of Miller and his associates already cited. At both temperatures there appear to be two slight hardness "peaks" of unknown significance.

The effect of temperature upon rate of spheroidization is quite marked. At 1000° F. spheroidization was hardly detectable even after 5000 hr. (about 7 months), but at 1100, 1200 and 1300° F. the rate was increasingly rapid, spheroidization being first apparent after about 300, 50 and 5 hr. respectively. The increase is shown diagrammatically in Fig. 1. When plotted on either semilogarithmic or double-logarithmic coordinates the data fall on an approximately straight line which, extrapolated to 900° F., indicates that spheroidization might begin at 900° F. in about 50,000 hr. — say six years.

The photomicrographs illustrate the relative amount of spheroidization observed in a single material under



Effect of Time at Temperature on Microstructure of Normalized Molybdenum Steel. 500×

specific conditions of time and temperature. They may not apply directly to other materials, or even to all 0.5% molybdenum steels. Chemical composition may be expected to have some influence; in an earlier study, R. F. Miller, W. G. Benz and W. E. Unverzagt of U. S. Steel Corp. Research Laboratories ("The Creep of Seventeen Low Alloy Steels at 1000° F.", *Proceedings* of the American Society for Testing Materials for 1940, p. 771) have found that the rate of spheroidization of molybdenum steel is decreased by the addition of chromium.

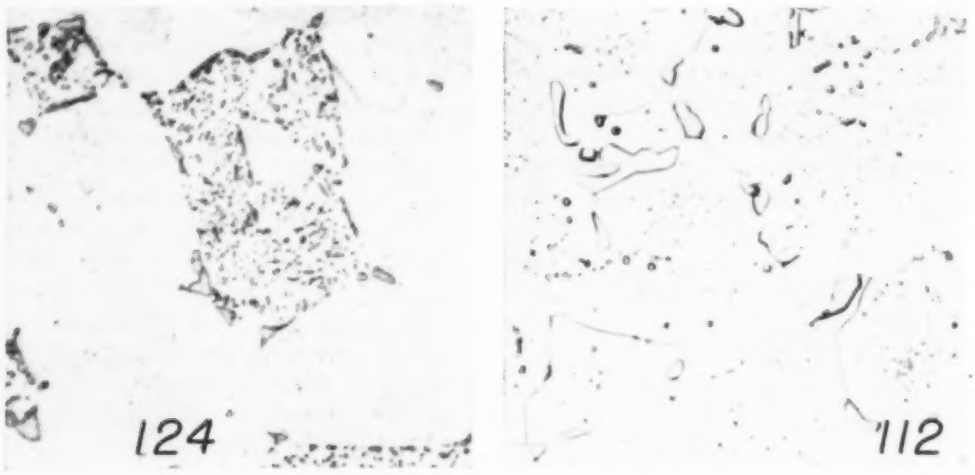


Fig. 2 — Control Sample (at Left) After 3000 Hr. at 1100° F. At right is a sample of another steel of same nominal grade, after about 30,000 hr. of actual service at temperature reported to be about 1100° F. Etched with picral; 1000×

Likewise, steelmaking practice — especially deoxidation — has its influence; the paper by Smith, Miller and Tarr quoted at the outset shows that there is a slight, but definite, tendency for spheroidization to proceed faster the greater the amount of aluminum used in deoxidation. The present material, of the older so-called fine-grained type, deoxidized with silicon and not less than 1.5 lb. aluminum per ton of steel, may therefore be expected to spheroidize more readily than the newer coarse-grained type of molybdenum steel deoxidized with silicon and not more than 0.5 lb. aluminum.

The rate of spheroidization may vary, even in the same heat of steel, depending on the mechanical and thermal history of the material. For example, annealed material takes considerably longer to spheroidize than does normalized material, presumably because of the coarser initial carbide lamellae. The rate of spheroidization may also be accelerated by cold working, and by the "hot work" of deformation which occurs during a creep-rupture test.*

However that may be, our examination of the structure of specimens after creep test indicates that stress of the order of that used in design has no significant effect on the rate of spheroidization. Accordingly it is believed that our photomicrographs, obtained on specimens held at temperature under no load, are typical of the trends likely to be encountered in such material when it is in service at elevated temperature.

The absence of graphitization was rather surprising in view of the fact it is generally believed (as proved by many papers and discussions before the American Society of Mechanical Engineers and others) that fine-grain deoxidation practice is conducive to graphitization of the finished steel.

The importance of an appreciation of the possible change in a steel exposed to high temperature for an extended period lies in the fact that the change is accompanied by a loss of strength. As illustration, Weaver† has estimated that a normalized 0.5% molybdenum steel, if spheroidized for about 10,000 hr. at 1000° F. (13 months), loses about half its initial creep strength. (His steel was of the fine-grained aluminum-killed type which, as mentioned above, spheroidizes slightly more rapidly than coarse-grained steel.) Accordingly, equipment designed on the basis of the strength for a given microstructure, and subjected to a temperature at which the carbide spheroidizes, may suffer a significant loss of strength during service at such temperature.

The rapid increase in rate of spheroidization above 1000° F. should also be emphasized, since more spheroidization can be produced by a few hours at 1200 or 1300° F. than by months or years at 900 or 1000° F.

*C. H. M. Jenkins, G. A. Mellor and E. A. Jenkinson, "Investigation of the Behavior of Metals Under Deformation at High Temperatures. Part II. Structural Changes in Carbon Steels Caused by Creep and Graphitization". *Journal* of the Iron and Steel Institute, V. 145 (1942), p. 51.

†S. H. Weaver, "The Effect of Carbide Spheroidization Upon the Creep Strength of Carbon-Molybdenum Steel", *Proceedings* of the American Society for Testing Materials, V. 41 (1941), p. 608.

The present article (as well as its continuation next month) by Mr. Downing and his associates has a general interest because it describes in detail how routine data accumulated from a group of 89 large forgings over a period of time can be analyzed to point the way to an improved product

Magnetic Properties of Generator Rotors as Affected by Composition

FOR SEVERAL YEARS many turbine-generator designers have been saying that, in effect, more importance must be attached to magnetic properties of generator rotor forgings. Their primary and immediate desire is for less deviation from the anticipated average magnetic properties. A second, but equally urgent, objective is a general improvement in magnetic properties without widening the deviation of results from the average. The ultimate goal, in fact, might well be a purchasing specification which covers magnetic properties in addition to those that exist today for physical properties and chemical analyses.

"Magnetic properties" in the last sentence means the amount of magnetic flux which would be forced through the forging by a given magnetomotive force. The more magnetic flux for a given magnetomotive force, the better the forging magnetically.

Variations in this property are of considerable importance, inasmuch as they influence the field current required, and hence the field heating characteristics and stability characteristics of the generator when in operation. Uniformity of magnetic properties is further very important in that closer prediction of performance and more economical design are possible. Extreme variations in magnetic properties may require redesign of rotor or stator, if the forging is to be used.

To learn something about these anomalies, a statistical study was made (at the suggestion of C. B. Fontaine of G.E.'s generator engineering division, and with his help) of the variations occurring in the d.c. magnetization values of 89 turbine-generator rotor forgings, all of them for units of less than 2000 kw., and of a type that forms a limited class of the forgings made at General Electric Co.'s Lynn River Works. Tests were made on specimens taken, according to our regular practice, in the tangential direction from the prolong of each forging, located at the top end (toward top of ingot) as shown in Fig. 1.

It should be emphasized that the magnetomotive force (m.m.f.) required to force flux through one of these forgings varies generally as about the 8th power of flux density. Consequently, a difference of only 3% in the flux-carrying capacity means a difference of about 25% in this component of required field current. In the discussion that follows, relative flux density values are quoted because of the manner of testing at the constant values of magnetizing force of 100, 200, 300, 400 and 500 amp.-turns per in., but variations in flux density values should be viewed in terms of the much larger resulting variation in required m.m.f.

The data that were accumulated for this study are considered accurate as far as they go, within the limits of standard testing procedures.

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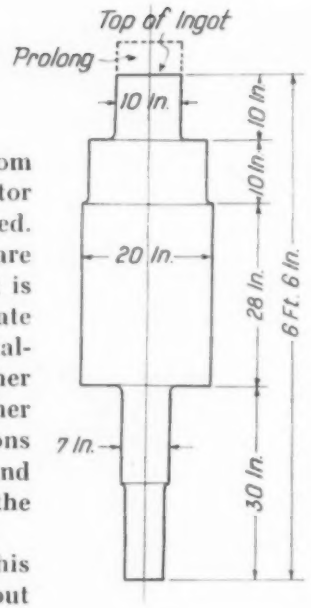
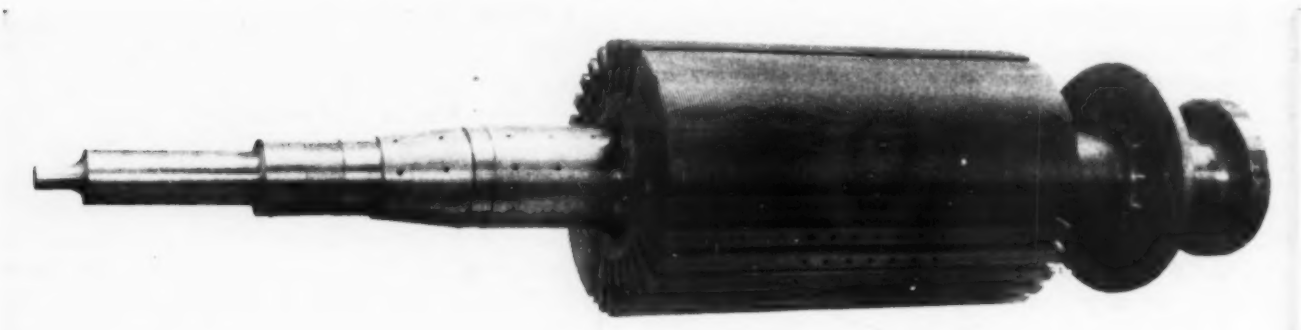


Fig. 1 — Sketch of Typical 2-Ton Forging Studied for Its Magnetic Properties

Some discussion drawn from allied studies on alloy steel rotor forgings will also be presented. Some of the conclusions are drawn with reservation, but it is hoped that they may stimulate more interest from the metallurgical viewpoint, and other interested persons may either accept or refute these conclusions and foster a more active and basic study — especially by the steel producers.

As mentioned previously, this investigation was carried out principally on data accumulated from 89 carbon-vanadium steel forgings (Fig. 1). This is a relatively small generator rotor forging, weighing only about 4000 lb. Figure 2 shows a rotor, finish machined.

Fig. 2 — Unwound Revolving Field for A.C. Turbine Generator, 3600 R.P.M., 60 Cycles, 2 Poles, Machined From Forging Shown in Fig. 1. Top end of ingot to right



Elements of Electrical Design

The rotor of a synchronous generator is essentially an electromagnet. The rotor of a high speed turbine-generator is usually constructed in the form of a long right cylinder and is mounted in bearings to rotate about the length axis of the cylinder. Longitudinal slots are cut in the cylindrical surface to carry the conductors of the field coils. These coils are connected in series to a pair of slip rings through which, by means of brushes, the exciting current (d.c.) is introduced.

Coils are so connected as to produce an even number of magnetic poles in the rotor, usually 2 or 4, which are alternately of north and south polarity. The rotor is mounted to rotate inside the stator, which is constructed in the form of a hollow cylinder made up of laminations of electrical sheet steel and provided in the inner cylindrical surface with longitudinal slots to carry the armature conductors.

The magnetic circuit of the machine* may be said to start from a pole of one polarity on the surface of the rotor and proceed across the air gap between the rotor and the stator, through the magnetic material of the stator, linking with the armature conductors, back through the stator material and air gap to a pole of opposite polarity on the face of the rotor and thence through the rotor material back to the pole assumed to be the starting point.

The total magnetomotive force (m.m.f.) in the machine is measured in ampere-turns, which is the product of the exciting current in amperes multiplied by the number of turns of field coil associated with each pair of poles. The magnetizing force is measured by the number of ampere-turns per in. of length of the magnetic circuit.

The field flux in the machine is measured in lines of magnetic force per sq.in. of cross section of the magnetic circuit. The flux proceeding from the surface of the rotor varies circumferentially in an approximately sinusoidal manner with respect to each pair of poles. This distribution of flux also exists in the stator structure and there is a periodic variation in space of the number of lines of force linking the armature conductors. When the rotor is rotated there is periodic variation in time of the number of lines of force linking each armature conductor, and it is this variation in the linkage which generates the voltage in the armature.

The voltage generated, which is the ultimate

*For this concise statement we are indebted to the late R. S. Davidson of the Thomson Laboratory.

Flux Density, Kilolines per Sq. In.

purpose of the machine, is a function of the intensity of the field flux in lines per sq.in., and the intensity of the field flux depends in part upon the magnetizing force and the magnetic quality of the rotor material. With better magnetic quality in the rotor material, a smaller magnetizing force is required to provide a given flux density in the magnetic circuit of the machine. This means, in general, a somewhat lower exciting field current, with corresponding lower field heating or increased capacity of the generator.

Now that the electrical and magnetic functions have been briefly outlined, it may be said that the steel forging must also have the required physical strength to be satisfactory for the mechanical stresses involved in its operation.

Test data contained in this article are, of course, all from laboratory work. They are thus conventional permeameter results, in which predetermined magnetizing forces (ampere-turns per in.) are applied to the test specimen and the magnetic flux measured. With the cross sectional area of the accurately ground specimen known, the results are then expressed in lines of magnetic flux or force (or kilolines) per sq.in. of steel.

The factors investigated for possible effect on the magnetic properties of these forgings are as follows: Chemical composition, heat treatment, physical properties, microstructure, and amount of forging. All but the first will be discussed in a subsequent article.

Effect of Chemical Composition

Although the investigation was concerned with forgings made to one specific drawing, two different billet materials were actually used. The range of chemical compositions for the usual elements in these two billet materials is:

	Class B	Class C
Carbon	0.35 to 0.45%	0.42 to 0.50%
Manganese	0.40 to 0.80	0.40 to 0.80
Silicon	0.15 to 0.35	0.15 to 0.35
Phosphorus	0.05 max.	0.05 max.
Sulphur	0.05 max.	0.05 max.
Vanadium	0.08 to 0.12	0.08 to 0.12

Correlation of average carbon content, average yield strength, and average d.c. magnetization tests for these two billet classes is shown below. For magnetic deviations (at 500 amp.-turns) with carbon content, see Fig. 3. Deviations of yield strength from the average will be shown in the next article.

	Class B	Class C
Number of forgings	66	23
Average carbon	0.403%	0.454%
Average yield (0.0002 in. per in.)	46,000 psi.	50,600 psi.
Average d.c. magnetization value (kilolines per sq.in.)		
at 100 amp.-turns per in.	99.2	97.0
200	108.8	107.5
300	114.1	112.8
400	118.1	116.8
500	121.1	119.8

Three types of heat treatment — *(a)* equalize and anneal; *(b)* equalize, anneal, single normalize and temper; *(c)* equalize, anneal, double normalize, and temper — were used. (The term "equalize" as here used means transferring the piece immediately after forging to a furnace which is at 1450° F. and holding until thermal equilibrium is reached, after which the forging is air cooled to 600° F. for grain refinement.) Since all three types of heat treatment occurred in a random manner in both the Class B and Class C billets, the above data show rather conclusively that the lower carbon billets produced somewhat better magnetic properties. The lower carbon billets also resulted in lower physical properties — as would be expected.

Although the differences in d.c. magnetization are small, the previous remark must be remembered — that this difference is greatly multiplied when m.m.f. is considered. This is a very important consideration, *provided* the difference is real and can be duplicated. In order to ascertain this, a statistical method of analysis, known as the "t" test, was used to determine whether the data are from one or two populations. It was then found that the difference in d.c. magnetization between the two billet classes is highly significant, with a probability of less than 1% that the two groups are alike.

Figure 3 shows carbon content plotted against d.c. magnetization at 500 amp.-turns per in. for forgings having similar heat treatments (equalize,

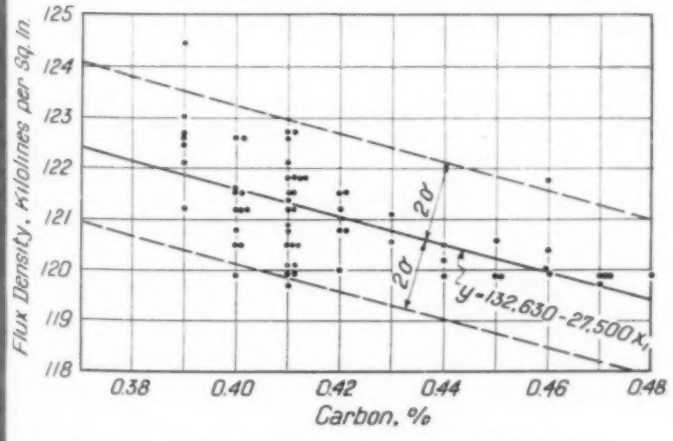


Fig. 3 — Carbon Content Vs. D.C. Magnetization at 500 Amp.-Turns per In. of 65 Billets of Both Class B and Class C Having the Same Heat Treatment — Equalize, Anneal, Normalize, Temper

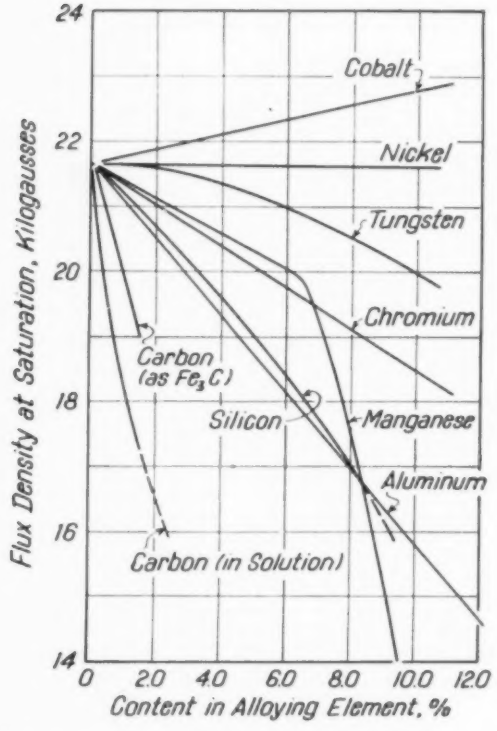


Fig. 4 — Effect of the Principal Elements in Alloy Steel on the Flux Density at Saturation. (From "Magnetically Soft Materials", by T. D. Yensen, A.S.M. Transactions, Vol. 27, 1939)

anneal, normalize, and temper). The inclined line was located by the method of least squares. Since other factors in addition to carbon content affect d.c. magnetization, the spread of values for a given carbon content is to be expected. The limit lines* shown in the diagram, which are $\pm 2\sigma$, actually bound all but four determinations.

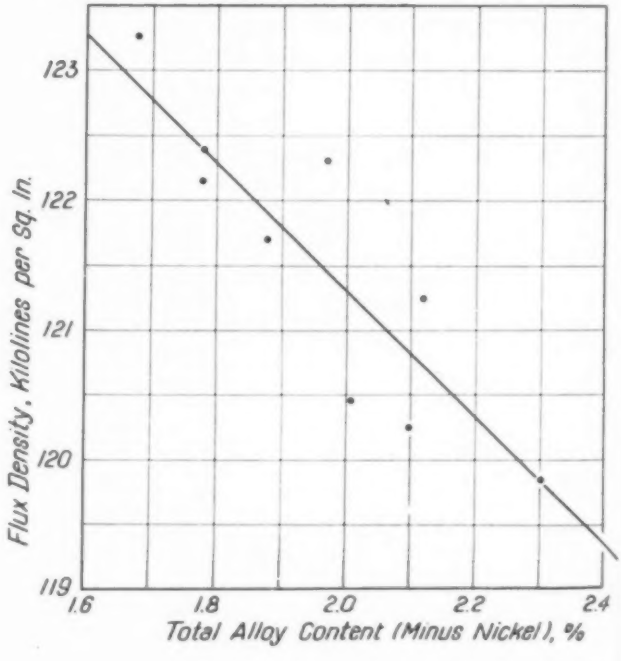
It should also be realized that the carbon contents reported are values taken from the vendor's certificates of test, and these give only the heat analyses. A considerable number of forgings are obtained from each heat, and although the carbon within a heat may vary from 5 to 10 points (hundredths of a per cent), all forgings from a given heat are considered to have the same analysis (as reported on the certificate). The carbon content for the individual forgings could not be determined, since test specimens were no longer available. These circumstances would naturally influence to a considerable degree the spread in the d.c. magnetization values which show up when plotted against carbon content. However, Fig. 3 shows graphically the beneficial effect of lower carbon in spite of the foregoing limitations.

Studies were also made on the effect of manganese, which was the only element besides carbon which varied to any extent. No apparent correlations could be found, but the effects of all the other variables could not be eliminated. However, any effect of manganese must be very slight, at least for the range covered in this investigation — 0.60 to 0.74%.

Because the certificates of test showed vanadium to vary within the extremely small limits of 0.10 to 0.12%, no attempt could be made to correlate its effect on magnetic properties. It is believed that vanadium in such small quantities has no appreciable effect, but that if it were permitted to increase substantially it would be detrimental because of its strong carbide-forming tendencies.

T. D. Yensen studied the effect of several elements on the magnetic saturation of iron. His curve for nickel (on Fig. 4) explains its harmlessness when present at about 2% in some of the higher strength, alloy steel rotor forgings. In turn, the addition of nickel (a ferrite strengthener) allows for a reduction in carbon, and this is known by Yensen's work, as well as our own analysis outlined above, to be of pronounced benefit.

Fig. 5 — Effect of Total Nonferrous Elements Except Nickel (C+Mn+Si+P+S+Cr+Mo+V) on D.C. Magnetization Values of Ni-Mo Alloy Steel Rotor Forgings at 500 Amp.-Turns per In.



In an allied investigation on nickel-molybdenum steel rotor forgings, we plotted d.c. magnetization values at 500 amp.-turns per in. against *total* alloy content, excluding nickel, and it was noticed that a fairly definite relationship exists.

*Theoretically the plus and minus "standard deviation" will bound 68¼% of the observations, $\pm 2\sigma$ bound 95%. Standard deviation σ of a group of data is computed by squaring each observed value, totaling the squares, dividing by number of observations, subtracting the square of the arithmetic mean and taking the square root of the difference.

Electric furnace experts talk shop and consider the origin of inclusions (dirt) and try to evaluate their metallurgical significance. New techniques such as manufacture of semikilled steel and small ingots were also discussed

Clean Steel From Electrics

Reported by S. W. Poole
Metallurgical Dept.
Republic Steel Corp.
Canton, Ohio

THE ELECTRIC FURNACE Steel Committee of the American Institute of Mining and Metallurgical Engineers held its fifth conference in Pittsburgh early in December, and presented to a large attendance a group of discussions about the refining process on acid and basic bottoms, ingot practice, and the production of clean steels. A notable additional feature was a movie and talks by A. O. Oltrogge of General Electric Co. and F. W. Cramer of Carnegie-Illinois Steel Corp. on the fundamental electrical engineering of the furnace and its controls — a session intended primarily for furnace helpers, observers, and metallurgical students.

Acid Steel — In a discussion of acid steels with higher silicon than normal, C. K. Donoho, metallurgist of American Cast Iron Pipe Co., presented some data from which he derived the following conclusions:

1. Silicon-killed steels can be cast sound in green sand without aluminum deoxidation; however, the silicon content required for soundness increases with increasing carbon.

2. If silicon is much higher than required for soundness there may be a reversion to pinhole porosity.

3. Inordinately high pouring temperatures cause greater tendency toward pinhole formation with silicon-killed steels.

4. By increasing silicon instead of using aluminum, cast steel of superior ductility for a given strength level is obtained.

S. F. Carter of the same firm presented figures relating some melting variables to the tensile properties of aluminum-killed 0.25% carbon acid electric steel, gained from surveying production for two years. It has been known that ductility is affected by certain variations in furnace prac-

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See Fig. 5. The small increase in total alloy content from 1.7 to 2.3% corresponds to a change in the plotted d.c. magnetization values from 123.2 to 119.9 kilolines per sq.in. In preparing Fig. 5 no attempt was made to weigh the varying effects of the individual elements, as would seem to be necessary by Fig. 4. These other elements which were added to give total alloy content were: C, Mn, Si, P, S, Cr, Mo, and V. The carbon contents concerned in Fig. 5 range from 0.29 to 0.37 and average 0.33%. It seems highly probable that a departure of even a few points of carbon from these extremes would make the curve invalid, because the effect of carbon would overshadow that of total alloy content.

Continuation

Further detailed analysis of the test data on these 89 forgings, correlating heat treatment and the resulting microstructure and physical properties, as well as deoxidation practice and reduction in forging, will be presented in Part II of this article in February.

tice, and some of Mr. Carter's conclusions as to factors productive of steel with the best tensile properties are:

1. As soon as melted, a high concentration of iron oxide should be produced, to lower the residual silicon and manganese, impart fluidity to inclusions, and aid in removing hydrogen.

2. A meltdown should be established high enough in carbon to permit a satisfactory carbon drop during oxidation. This will produce a good flushing action of carbon monoxide, removing hydrogen, nitrogen and inclusions without carrying the slag to a low iron oxide (FeO) content. Slightly poorer tensile properties result if the FeO in slag gets too low.

3. For first deoxidation, which should not be too early, simultaneous manganese and silicon addition proved better than either element alone. Manganese and silicon should be added in time to complete their deoxidation before aluminum is introduced. This is known to minimize alumina inclusions.

4. Both oxidizing and reducing slag extremes proved detrimental to ductility.

An experimental program designed to evaluate the recovery of vanadium and other alloys was described by C. Wyman of Burnside Steel Foundry Co. and G. W. Johnson of the Vanadium Corp. of America. Twenty-four acid electric heats were made and the observations analyzed. There is evidence that a meltdown carbon of 0.50 to 0.60% is effective in retarding the oxidation of vanadium during the meltdown period. It was significant that best vanadium recoveries from the practices employed were obtained with strong reducing agents such as "Ferro-Carbo" (silicon carbide) and aluminum dross as additions to the slag. It was also evident that 80 to 90% of the vanadium contained in vanadium-bearing scrap can be reclaimed by control of FeO in the finishing stages of the heat. Furthermore, the uniformity of the FeO content in the slag through the finishing period — and especially at tap time — affects the mechanical properties of the finished steel. It was the authors' belief that considerably more work should be done in correlating results of heats in which the slag oxide contents are controlled, or the slag partially deoxidized.

The final technical session on acid steel was concerned with factors controlling slag volume. Twelve reports were made, starting with a review of known factors (presented by C. E. Locke of the West Michigan Steel Castings Co.). Other factors reported on were the effect of temperature, additions of iron ore, lime and manganese oxide. The time of heat, effect of metal depth, extent of bank, and bottom repairs were also considered.

Some important factors involved in slag volume in the acid electric furnace are *(a)* sources of silica, SiO_2, in the slag, from the silica sand furnace bottom, sand present on foundry scrap, and the oxidation of silicon in the scrap charged; *(b)* manganese oxide from oxidation of manganese in the scrap; *(c)* refining additions of FeO and MnO; *(d)* additions of CaO to reduce melting point of FeO-MnO-SiO_2 ternary slag system.

Too great a slag volume has the disadvantages of leading to cold heats and poor recovery of alloy elements, particularly manganese.

Production of Sound Ingots

The technical session on ingots was concerned with the production of the extremes in ingot sizes, from small 125-lb. ingots for direct bar rolling to a tremendous 108-in. octagon ingot weighing 545,700 lb. This latter ingot, one of the largest ever made, was described by F. B. Foley of The Midvale Co.

Casting of this 275-ton ingot necessitated the combining of metal from three 100-ton openhearth heats. The body of the ingot weighed 448,800 lb., which includes a bottom pool of about 7500 lb. of metal. The sinkhead weight was 96,900 lb. or about 18% of the total. Mold and ingot together weighed about 1,000,000 lb. (500 tons).

The mold was first filled 40 in. deep by bottom pouring 140,000 lb. through a runner. This provided a pool, and prevented splash when the mold was filled from this point on by pouring from a headbox through the top. The ladle nozzle was 3 in. and the headbox had a 2-in. nozzle. The ingot was poured in 3 hr. total time.

Further remarks of Mr. Foley were concerned with the purposes to be accomplished in casting metal into ingots. The function of an ingot mold is to provide a shape suitable for subsequent forging or pressing and to accomplish this end with a mass that is sound and as free as possible from segregation. The details of the shape — whether the section is round, octagonal, square or with a corrugated surface — whether the mold is cast large end up or not, the amount of taper and relative chill provided at top and bottom usually determine the metallurgical quality of the product.

R. L. Stephenson of Carnegie-Illinois Steel Corp., in his paper on problems associated with the production of sound ingots, stated that a criterion of ingot soundness is to be found on the basis of rejections due to cracking in semifinished blooms and billets. High pouring temperature and delayed delivery to the soaking pits is an outstanding factor in poor ingot quality. The 0.18 to 0.23% carbon range is particularly susceptible

to rejections from these causes. He believes that control of pouring temperature is a most important factor for satisfactory external conditions.

The long, slender ingots of semikilled electric furnace steel, with an 11-to-1 length-to-width ratio, designed for continuous rolling mill operation at the Connor Steel Co., evinced considerable interest. As described by B. C. Blake, these ingots vary in size from 3⅞x3¼x44 in. to 5x4x60 in. and are cast in molds weighing four times the ingot. These small, slender ingots contract readily and give good ingot-to-mold contact during cooling. Ingots are allowed to go cold in the mold, and as many as 600 ingots can be cast per mold.

The Dornin process of ingot production eliminates hot tops and conditions associated with the "stop-pour" line. Quality of the ingots is of very high grade; A.I.S.I. 52100 steels have been processed with a yield up to 92%. These points were emphasized in a discussion by W. J. Reagan of the paper presented by G. A. Dornin, Jr., of Dornin Molds. The process is unique with respect to the modifications involved in the production of an ingot of killed steel without a hot top. A steep taper mold is used with outside insulation to produce a pipe-free center axis. The isolation of the top segregate zone is accomplished by punching a depression in the top center and then upsetting the collar so formed, followed by forging the ingot to dimensions suitable for the blooming mill.

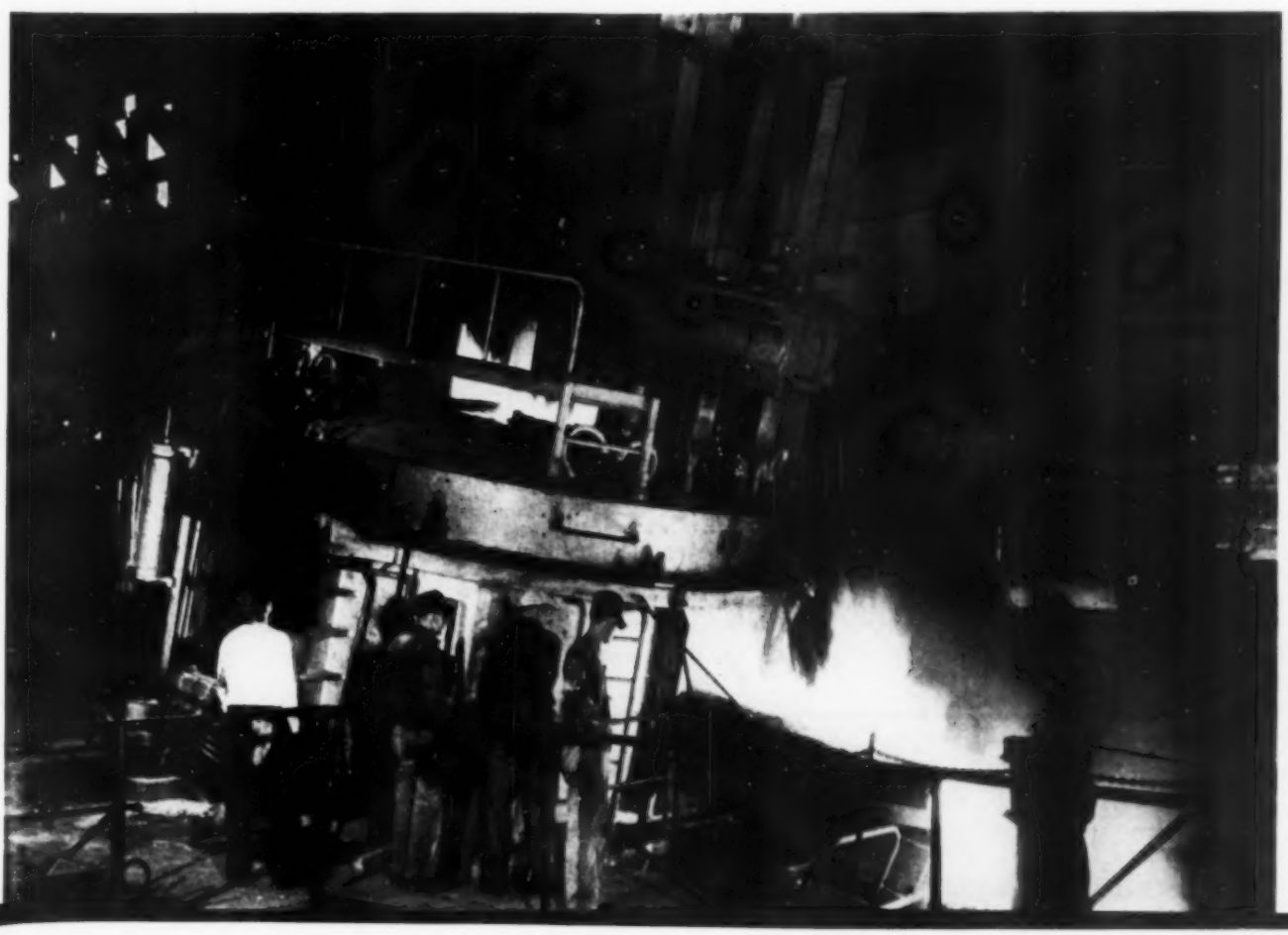
Metallurgy of the Process

The hydrogen and nitrogen contents of the finished steel as affected by melting practice were reviewed by C. E. Sims of the Battelle Memorial Institute, who studied 18 heats, including acid and basic electric and openhearth practice. The hot extraction method was used, by which hydrogen from the test sample is extracted in 40 hr. under a vacuum of 10^{-5} mm.

Nitrogen is easier to remove from steel than hydrogen, especially when present initially in large amounts. In the furnace bath, both gases can be removed during a strong active boil after meltdown. Hydrogen, however, in one 35-ton basic electric heat studied, increased during this period — due, presumably, to the use of damp iron ore or burnt lime. All the hydrogen swept out of the bath in the furnace can be regained in the ladle if it is not properly dried. Many examples of high hydrogen pickup were cited to illustrate this point. With a really dry ladle there is an actual loss of hydrogen after tapping. Newly lined ladles are a good source of hydrogen due to moisture in fireclay cement not easily removed in ordinary drying.

Quantitative study of hydrogen in openhearth steel is difficult during the heat, since an artificial atmosphere of partly burned fuel exists above the bath. When, for example, fuel oil is atomized by steam, considerable hydrogen can be present.

Tapping a Heat of Carbon Steel From the High-Powered Electric Arc Furnace of Northwestern Steel & Wire Co. at Sterling, Ill.



Atomic Energy Is *Your* Business

Extracts from an address by **David E. Lilienthal**,
Chairman, U.S. Atomic Energy Commission, Sept. 22, 1947.

THERE is a growing tendency in some quarters to act as if atomic energy were none of the American public's business. It isn't said in just those words, of course. It is put more discreetly. It is said that the subject is too technical for public discussion — or that "national security" requires that the public be kept in the dark, even on discussions of broad policy — or that the steps that need to be considered are such strong meat that all these matters must be withheld from the public. It is said, in support of this practice, that it was followed successfully in wartime, and hence should be continued today.

In my opinion this is plain nonsense, and dangerous nonsense — dangerous to cherished American institutions and for that reason dangerous to genuine national security.

Atomic energy and scientific discoveries have not and need not change the fundamental principles of democracy, which rest upon faith in the ultimate wisdom of the people when they have been truthfully and clearly informed of the essential facts.

What do you think of when you think of atomic energy? The chances are that you think only of the atomic bomb. This is natural enough. You are troubled, of course; concerned, uneasy — and you should be. The atomic weapon is real. I live with it, day and night, and I assure you that, however fantastic, it is plenty real. But scaring the daylights out of everyone so no one can think, inducing hysteria and unreasoning fear — this is not going to get anywhere — anywhere we want to go.

It is more important to understand that *atomic energy and atomic bombs are not synonymous.* To continue to think so is a major fallacy. What we have here actually is not simply a weapon. Here is newly acquired knowledge of great and universal forces comparable to the forces of gravity and the forces of electric charges and of magnetism.

I suppose there is nothing of a physical nature that is more friendly to man or more necessary to his well-being than the sun. This life-giving sun is itself a huge atomic energy factory. The forces within the atom are not new. Far from it. What *is* new is this: First, that mankind has learned more in the past 30 years about atomic forces than in all the preceding centuries, and second, that within the next few years — a decade perhaps — we should be in a position to unlock new knowledge about life and matter so great that wholly new concepts of human life will follow.

Such new knowledge inevitably brings changes that will affect you and yours, in your life in every community. Some of these changes are in process at this moment. Thus, the atomic weapon has changed the relations between nations and the problem of the maintenance of peace — and nothing could be closer to your life and that of your children than that. Atomic energy has already brought changes in the treatment of human suffering, and is at this moment adding to knowledge to be used in fighting cancer, heart ailments, and many other diseases. Radioactive materials from the Commission's plant at Oak Ridge are throwing a clear light upon some of the oldest mysteries of plant life. The entire investment in the atomic energy project — now nearly 2½ billion dollars — may be more than repaid by the benefits to agriculture and to human nutrition alone. New knowledge of little known metals opens up great prospects in industry. Some day the energy released by the splitting of the atoms of uranium and plutonium will provide a new source of electricity and heat.

New professions for your young people, new hope for the afflicted, new understanding of how science can serve for peace — these are among the items on the agenda of the present and immediate future.

These things are but a beginning. What is important to understand is not just what the precise effect of knowledge of these basic forces will be — which is necessarily speculative — but rather that *important changes will come.* What we should be concerned about is that the changes shall be fitted into the American way of doing things, not imposed upon us so that individual freedom is impaired. We must make sure that the American people will have a decisive say-so in the adjustments these discoveries will bring in community life, in our agricultural, educational, industrial and military institutions. You must make dead sure that your public servants, civil and military, legislative and executive, all understand clearly that atomic energy *is* your business, the people's business. You must not at your peril let these new technical advances get out of your power to control and direct. I warn you that this must not happen or the essence of the American scheme of things will be lost.

The whole problem of atomic energy comes down to this: First, we must find ways whereby mankind will not make use of these discoveries for destructive and evil ends, and second (and closely related to the first), we must find ways of stimulating the application of these discoveries to things that are beneficial to mankind and to the best of human aspirations. To what *use* will we put this great new ever-growing knowledge? *There* is the real question. It is not a scientific matter. What

Presentation of verbatim extracts from important contemporary documents concerning atomic energy does not imply that the Editor agrees with the opinions quoted, nor that they are expressions of A.S.M. policy.

this vast problem requires is not technical judgment, but rather the human experience and good sense of the natural leaders of opinion within the thousands of communities of the country. What is needed is sense about human relations, about standards of fairness, about principles of self-government and self-education.

How can you acquire sufficient information to make your judgment effective? I have some suggestions to offer along this line.

As to *what* you should know, remember that the information you need to have is not secret technical information, nor is it highly complicated, even on the scientific side. For what technical information you need, try your nearby colleges or your local high schools — and if their science teachers don't know enough about the subject to be able to explain it simply to the average layman, then you know there is something wrong with the teaching going on around you — and that is worth something in itself.

In providing information about atomic energy the U.S. Atomic Energy Commission has a responsibility, imposed by law. It is our hope that it can be discharged with good sense and restraint. The problem is chiefly one of getting nonsecret information into a form for your consideration that will be clear, interesting, and without bias. And for this you can properly expect great things of the press of the United States, the radio and the magazines. These, together with motion pictures, constitute one of the greatest educational forces in human history.

It is also most important that the facts and analysis of policies should come to you from a variety of sources, not from only one, and above all that they should *not* come solely from official sources. This variety will give you a chance to check one version against another, and draw your own conclusions. Don't be content to take ideas that have been pre-digested for you at some distant place. Put this on the programs of your Chamber of Commerce, the P.T.A., Rotary, 4-H clubs, veterans' organizations, professional organizations, the medical society — and so on. These are your organizations. You can speak your mind in your own town.

What I propose will mean some work. No doubt of that. Let me say this: Look upon this task of becoming familiar with the essentials of atomic energy as an obligation directly to your children. If schemers or fools or rascals or hysterical stuffed shirts get this thing out of your hands — it may then be too late to find out what it is all about.

Anyway, one idea helps me on my own job; the feeling I have deep in me that God the Father of us all did not make man in His image and endow him with capacity to learn nature's secrets in order that man may use that knowledge to destroy the human race. I believe the American people, thinking it over together in their home towns, and having it on their hearts, will work this thing out and make good sense of it. For in the conscience and the judgment of the people lies the strength of democracy.

During the discussion it was pointed out that the use of dry raw materials is more important during the refining period after completion of the boil, when the trend is for hydrogen in the bath to increase slowly. Furthermore, tarred ingot molds may or may not cause difficulty due to gas evolution, depending on the level of hydrogen present in the steel entering the molds.

At a well-attended session on the use of oxygen as a decarburizing agent in basic electric steel melting, J. H. Berryman of Air Reduction Sales Co. and J. M. Gainer of Linde Air Products Co. discussed the following factors:

1. Chromium loss in oxidizing carbon in the ordinary way by ore or sinter, when melting high-chromium heats. The high temperatures generated by oxygen injection favors less oxidation of chromium, while carbon may be oxidized at these higher-than-usual temperatures to extremely low values.

2. Power savings of up to 20% are possible, due to the exothermic nature of reactions with oxygen gas.

3. Oxygen injection is claimed to be no worse on furnace bottoms than normal practice.

4. Cleaner steel usually results from the more vigorous boil when injecting oxygen.

Future possibilities with the use of oxygen in the electric furnace are concerned with development of a stack type of roof to carry off fume and gases, and the use of auxiliary oil-oxygen burners. A combination of ore and oxygen additions may also be of benefit, so that the endothermic ore reaction can be used to lower the bath temperature when desired.

Some data were presented — cu.ft. of oxygen per point (0.01%) of carbon, per ton of ingot — to show the amount of oxygen necessary to remove carbon in oxidizing several types of steel:

Foundry grades	3 to 7 cu.ft.
Low-carbon openhearth grades	2 to 7
A.I.S.I. 52100	1 to 6
High-chromium steels	20 to 100

Cleanliness of Steel

At a joint acid and basic technical session, an evaluation of steel cleanliness was presented by Philip Schane, Jr., of the Carnegie-Illinois Steel Corp. He enumerated some reasons for the importance of clean steel as:

1. The adverse effect of inclusions on highly stressed parts, particularly at high hardness levels.

2. The harmful effects on highly polished surfaces, as in stainless steel sheet.

3. A lowering of transverse ductility, as in gun tube steels. (A distribution of round-type inclu-

sions was stated to be most satisfactory for transverse ductility.)

As far as steel melting practice is related to the inclusion problem, the desirability of a vigorous carbon boil after meltdown was emphasized. After slagging off, equilibrium conditions between carbon and oxygen in the bath should be attained without using an excess of deoxidizer. A fluid finishing slag, low in FeO and kept in a deoxidizing condition, should be maintained.

Reoxidation on tapping and pouring will occur and this exposure should be of as short a duration as possible, especially when aluminum is present. Presence of some furnace slag in the bottom of the ladle should aid in minimizing the oxidation of aluminum during tapping. Opportunity for inclusions to float out of the ladle should be allowed, and the ingots poured with a good solid stream.

Control of deoxidation, together with other factors involved in melting practice, to produce consistently heats of high quality alloy steel to stringent nonmetallic inclusion specifications is a problem of considerable magnitude, in the opinion of S. W. Poole of Republic Steel Corp. One important factor involved is deoxidation practice, and in this respect much fundamental work has been done on establishing carbon-oxygen equilibrium for openhearth and electric furnace melting. The effect of deoxidation sequence on total oxygen content after initial deoxidation, at tap and in the ingot, has been demonstrated — at least for openhearth steels. This important information needs to be supplemented by a consideration of different deoxidation practices on quality ratings, and determination (by metallographic and other means) of the identity of the nonmetallic inclusions formed in large production heats.

When studying the formation of inclusions sampling of a steel bath leads to difficulties due to the extremely fine inclusions in the rapidly cooled small tests. Inclusions formed during solidification in commercial ingots are larger, and also more numerous due to precipitation on slow cooling and coalescence.

X-ray diffraction methods can be used in the study of inclusions for accurate identification of mineral phases present. Such methods are a useful aid to the metallographer and petrographer.

The effect of refractories on steel cleanliness was reviewed by J. G. Mravec of Timken Roller Bearing Co., Steel and Tube Division. A summary of his views includes the following:

1. Basic inclusions, such as might originate from the furnace bottom and banks, have not been encountered in steel samples and hence the effect of bottom refractories on steel cleanliness is considered to be nil — or at most very small.

2. Occurrence of entrapped refractory inclusions in steel is rather infrequent and their distribution is random (they were, in the speaker's experience, found only once in approximately every 200 bloom and bar etch tests).

3. There is no practical way or means of determining the exact origin of entrapped refractory material in the steel. The use of radioactive tracers has been suggested. At present the study of the effects of various refractories on steel cleanliness is difficult and indefinite.

4. Many types of highly refractory materials have been used in runners, ladles and nozzles, but in general they proved no more beneficial than conventional fireclay refractories.

5. Control of pouring temperature is the greatest single factor affecting steel cleanliness.

Gilbert Soler of Atlas Steels, Ltd., in the discussion of these papers, stated that there is an overemphasis on cleanliness in steel. The statistical number of samples taken is usually insufficient to evaluate the cleanliness of a heat. "Quality testing" is at present not an exact science.

Second Slag for Wash

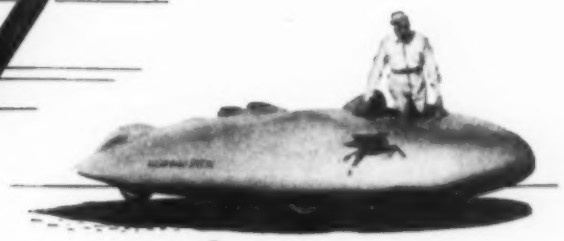
Another interesting feature of this program was an abstract of a paper by Georges Ranque, Société Commentry-Fourchambault, France, on a rational process for the improved manufacture of steel without inclusions. This was presented by Shadburn Marshall of Carnegie-Illinois Steel Corp. With this practice ferro-alloys are added after a clean slag-off, while the superheated bath is at its highest temperature and in an oxidized condition. It is believed that the large amounts of inclusions contained in ferro-alloys will then have a chance to rise out of the bath, together with other products of prior oxidation. A second slag is made to which is progressively added a strong reducing agent, such as crushed 85% ferrosilicon or calcium silicide, to reduce the oxidized alloy elements in the slag resulting. Deoxidation is then accomplished by a slag practice.

The comments of C. E. Sims on this French process were concerned with the needless worry over large exogenous inclusions introduced early, since such inclusions can float out rapidly. The inclusions resulting from deoxidizing and alloy additions also are easily eliminated. A considerable number of inclusions actually form while the steel is cooling during pouring, and during solidification in the mold, due to shifts in equilibrium on falling temperatures. Mr. Sims feels that large inclusions originate late in the heat and during the final pouring stages.

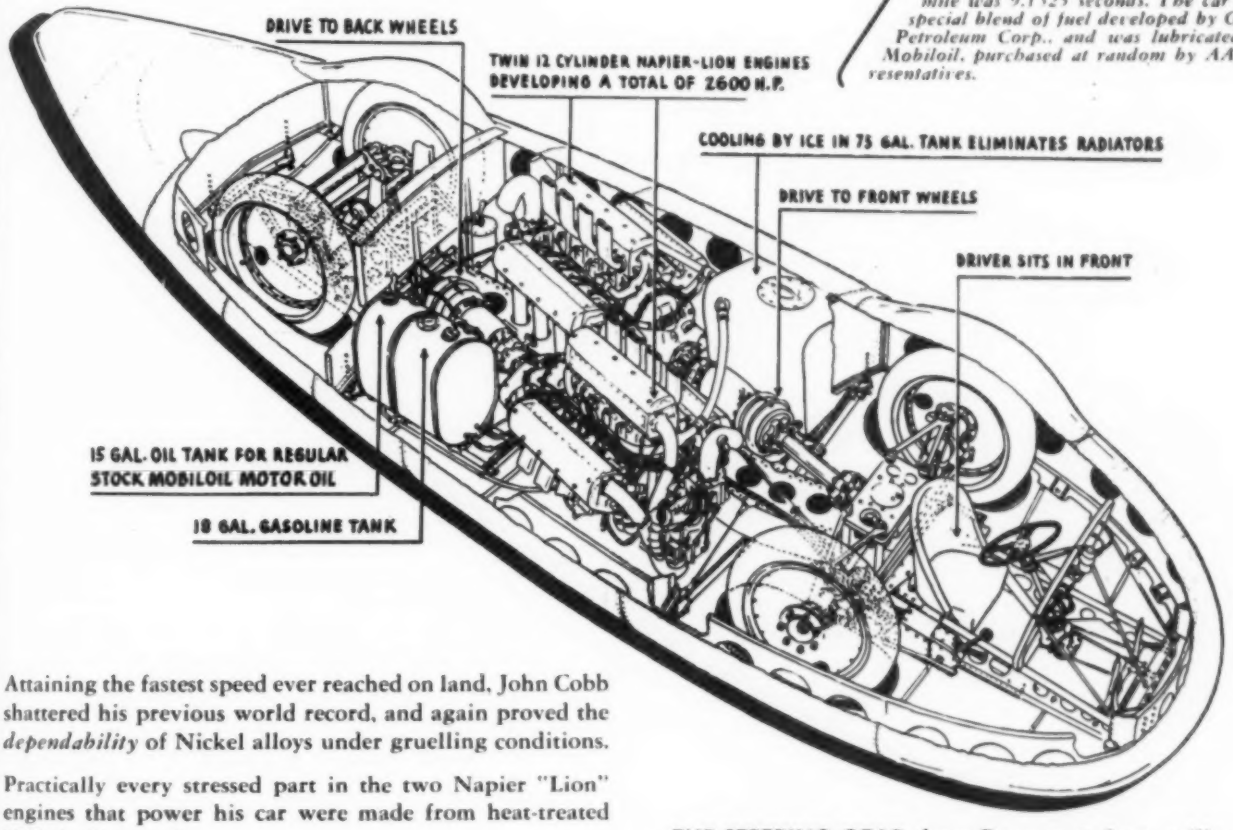
400 MPH

WITH THE HELP OF

NICKEL ALLOYS...



John Cobb drove this "Railton Mobil Special" over the measured mile on the Bonneville Salt Flats in 8.93 seconds . . . a speed exceeding 403 miles per hour. His average time for the mile was 9.1325 seconds. The car used a special blend of fuel developed by General Petroleum Corp., and was lubricated with Mobiloil, purchased at random by AAA representatives.


DRIVE TO BACK WHEELS
TWIN 12 CYLINDER NAPIER-LION ENGINES DEVELOPING A TOTAL OF 2600 H.P.
COOLING BY ICE IN 75 GAL. TANK ELIMINATES RADIATORS
DRIVE TO FRONT WHEELS
DRIVER SITS IN FRONT
15 GAL. OIL TANK FOR REGULAR STOCK MOBILOIL MOTOR OIL
18 GAL. GASOLINE TANK

Attaining the fastest speed ever reached on land, John Cobb shattered his previous world record, and again proved the *dependability* of Nickel alloys under gruelling conditions.

Practically every stressed part in the two Napier "Lion" engines that power his car were made from heat-treated Nickel alloy steels.

ALL PINIONS, GEARS AND SHAFTS in the differential and transmission, supplied by Firth-Derihon Stamping, Ltd., were made from an electric furnace Nickel-chromium casehardening steel, containing 4.3 percent Nickel.

THE UNIQUE UNIVERSAL JOINTS made for this car by Laycock Engineering Co., utilize a 3½ percent Nickel steel spline shaft joined to the housing with bolts of the same Nickel content.

THE SPEEDSTER'S FRAME was produced by John Thompson Motor Pressings, Ltd., in Nickel alloyed steel with a minimum tensile strength of 100,000 p.s.i.

THE STEERING GEAR, from Burman & Sons, utilizes two Nickel steels and one Nickel-chromium-molybdenum steel, heat treated to high strength and toughness.

WHEELS FOR THIS CAR are the same ones made by Dunlop Rim & Wheel Co., Ltd., for Cobb's 1939 record run. They incorporate rims produced from forged rings of a 3½ percent Nickel steel and held together on each wheel by bolts of "18-2" stainless steel, heat treated prior to machining.

Nickel alloys have established notable records in exacting applications. The many compositions available permit selecting the one with extra qualities for a specific use. Discuss your individual metal problems with our technical staff. Write us today.

EMBLEM OF INCO SERVICE
TRADE MARK

Over the years, International Nickel has accumulated a fund of useful information on the selection, fabrication, treatment and performance of engineering alloy steels, stainless steels, cast irons, copper-base and other alloys containing Nickel. This information is yours for the asking. Write for "List A" of available publications.

THE INTERNATIONAL NICKEL COMPANY, INC. 67 WALL STREET NEW YORK 5, N. Y.

Standard Stainless Steels, Wrought and Cast

Wrought Stainless Steels *(a)*
(American Iron and Steel Institute Designations; April 1947)

Type No.	Carbon	Chromium	Nickel	Other Elements *(b)*	S.A.E. No. *(c)*
301	0.08-0.20	16.0-18.0	6.0- 8.0		30301
302	0.08-0.20	17.0-19.0	8.0-10.0		30302
302-B	0.08-0.20	17.0-19.0	8.0-10.0	Si 2.00-3.00	
303	0.15 max.	17.0-19.0	8.0-10.0	P or S or Se 0.07 min. Mo or Zr 0.60 max.	30303-F
304	0.08 max.	18.0-20.0	8.0-11.0		30304
305	0.12 max.	17.0-19.0	10.0-13.0		30305
308	0.08 max.	19.0-21.0	10.0-12.0		
309	0.20 max.	22.0-24.0	12.0-15.0		30309
310	0.25 max.	24.0-26.0	19.0-22.0	Si 1.50 max.	30310
314	0.25 max.	23.0-26.0	19.0-22.0	Si 1.50-3.00	
316	0.10 max.	16.0-18.0	10.0-14.0	Mo 2.00-3.00	30316
317	0.10 max.	18.0-20.0	11.0-14.0	Mo 3.00-4.00	30317
321	0.08 max.	17.0-19.0	8.0-11.0	Ti is 5 × C (min.)	30321
	0.25 max.	7.0-10.0	19.0-23.0	Cu 1.00-1.50	30325
347	0.08 max.	17.0-19.0	9.0-12.0	Cb is 10 × C (min.)	30347
403	0.15 max.	11.5-13.0		Turbine quality Si 0.50 max.	
405	0.08 max.	11.5-13.5		Al 0.10-0.30	
406	0.15 max.	12.0-14.0		Al 3.50-4.50	
410	0.15 max.	11.5-13.5			51410
414	0.15 max.	11.5-13.5	1.25-2.50		51414
416	0.15 max.	12.0-14.0		P or S or Se 0.07 min. Mn 1.25 max. Mo or Zr 0.60 max.	51416-F
420	Over 0.15	12.0-14.0			51420
	0.30-0.40	12.0-14.0		*(d)*	51420-F
430	0.12 max.	14.0-18.0			51430
430-F	0.12 max.	14.0-18.0		P or S or Se 0.07 min. Mn 1.25 Mo or Zr 0.60 max.	51430-F
431	0.20 max.	15.0-17.0	1.25-2.50		51431
440-A	0.60-0.75	16.0-18.0		Mo 0.75 max.	51440-A
440-B	0.75-0.95	16.0-18.0		Mo 0.75 max.	51440-B
440-C	0.95-1.20	16.0-18.0		Mo 0.75 max.	51440-C
	0.95-1.20	16.0-18.0		*(e)*	51440-F
	0.20 max.	18.0-23.0			51442
446	0.35 max.	23.0-27.0		N_2 0.25 max. Mn 1.50 max.	51446
501	Over 0.10	4.0- 6.0			51501
502	0.10 max.	4.0- 6.0			

Cast Stainless Steels
(Alloy Casting Institute Designations; October 1947)

Type No. *(f)*	Carbon	Silicon (Max.)	Chromium	Nickel	Other Elements *(g)*
CA-15	0.15 max.	1.50	11.5-14.0	1.0 max.	Mo 0.5 max.
CA-40	0.20-0.40	1.50	11.5-14.0	1.0 max.	Mo 0.5 max.
CB-30	0.30 max.	1.00	18.0-22.0	2.0 max.	
CC-50	0.50 max.	1.00	26.0-30.0	4.0 max.	
CE-30	0.30 max.	2.00	26.0-30.0	8.0-11.0	
CF-8	0.08 max.	2.00	18.0-21.0	8.0-11.0	
CF-20	0.20 max.	2.00	18.0-21.0	8.0-11.0	
CF-8C	0.08 max.	2.00	18.0-21.0	9.0-12.0	Cb 8 × C *(h)*
CF-8M	0.08 max.	1.50	18.0-21.0	9.0-12.0	Mo 2.0-3.0
CF-12M	0.12 max.	1.50	18.0-21.0	9.0-12.0	Mo 2.0-3.0
CF-16F*	0.16 max.	2.00	18.0-21.0	9.0-12.0	Mo 1.5 max. P 0.17 max. Se 0.20-0.35
CF-16F*	0.16 max.	2.00	18.0-21.0	9.0-12.0	Mo 0.40-0.80 S 0.20-0.40
CG-12	0.12 max.	2.00	20.0-23.0	10.0-13.0	
CH-10	0.10 max.	2.00	22.0-26.0	12.0-15.0	
CH-20	0.20 max.	2.00	22.0-26.0	12.0-15.0	
CK-20	0.20 max.	2.00	23.0-27.0	19.0-22.0	
HC	0.50 max.	2.00	26.0-30.0	4.0 max.	Mo 0.5 max. *(i)*
HD	0.50 max.	2.00	26.0-30.0	4.0- 7.0	Mo 0.5 max. *(i)*
HE	0.20-0.50	2.00	26.0-30.0	8.0-11.0	Mo 0.5 max. *(i)*
HF	0.20-0.40	2.00	18.0-23.0	8.0-12.0	Mo 0.5 max. *(i)*
HH	0.20-0.50	2.00	24.0-28.0	11.0-14.0	Mo 0.5 max. *(i)* N 0.2 max.
HI	0.20-0.50	2.00	26.0-30.0	14.0-18.0	Mo 0.5 max. *(i)*
HK	0.20-0.60	3.00	24.0-28.0	18.0-22.0	Mo 0.5 max. *(i)*
HL	0.20-0.60	3.00	28.0-32.0	18.0-22.0	Mo 0.5 max. *(i)*
HT	0.35-0.75	2.50	13.0-17.0	33.0-37.0	Mo 0.5 max. *(i)*
HU	0.35-0.75	2.50	17.0-21.0	37.0-41.0	Mo 0.5 max. *(i)*
HW	0.35-0.75	2.50	10.0-14.0	58.0-62.0	Mo 0.5 max. *(i)*
HX	0.35-0.75	2.50	15.0-19.0	64.0-68.0	Mo 0.5 max. *(i)*

*Alternate types.

Notes

(a) All composition ranges are based on ladle analysis. For standard permissible variations from specified chemical ranges or limits for check analysis, see pages 10 to 13, Section 24, A.I.S.I. Steel Products Manual.

(b) **Manganese:** 2.00 max. in all 300 types except S.A.E. 30325 which has 0.60 to 0.90; 1.00 max. in all 400 and 500 types except 416 (1.25 max.), 430-F (1.25 max.) and 446 (1.50 max.). **Silicon:** 1.00 max. in all types except 302-B (2.00 to 3.00), 310 (1.50 max.), 314 (1.5 to 3.0), S.A.E. 30325 (1.00 to 2.00) and 403 (0.50 max.). **Phosphorus** is 0.40 max. and **sulphur** is 0.30 max. in all types except 303, 416, 430-F, in each of which they are 0.07% min. if added for improving machinability.

(c) S.A.E. composition limits may be slightly different from the A.I.S.I. analyses quoted.

(d) Same as in 51416-F and 51430-F.

(e) Same as in 51416-F except that Mn or Zr is 0.75 max.

(f) Designations with the initial letter C indicate alloys generally used to resist corrosive attack at temperatures less than 1200° F. Designations with the initial letter H indicate alloys generally used under conditions where the metal temperature is in excess of 1200° F.

(g) **Manganese:** 1.00 max. in CA-15, CA-40, CB-30 and CC-50; 1.50 max. in all other C alloys; 1.00 max. in HC; 1.50 max. in HD; 2.00 max. in all other H alloys. **Phosphorus** and **sulphur:** each 0.04 max. in all alloys except CF-16F regular, wherein P is 0.17 max., and in CF-16F alternate, wherein S is 0.20 to 0.40.

(h) Columbium 1.00% max.

(i) Molybdenum not intentionally added.

Data are presented from a study of Charpy keyhole notch specimens and hardnesses of some aluminum and magnesium alloys and steels used in aircraft construction, when refrigerated down to temperatures close to absolute zero.

Impact Strength and Hardness of Aircraft Alloys Down to —423° F.

By M. G. Fontana and J. L. Zambrow
The Ohio State University
Columbus, Ohio

INFORMATION on mechanical properties of metals and alloys is quite extensive for normal and elevated temperatures, but there is a dearth of data for low temperatures, particularly very low temperatures. This paper covers the results of impact and hardness tests made for Air Materiel Command on a variety of metals and alloys in the temperature range +20° C. to −253° C. (20° above absolute zero or −423° F.).

Materials — The metals and alloys studied are often used for aircraft construction. These materials include 2S-¾H, 24S-T, 61S-T and 75S-T aluminum alloys, Dowmetal FS-1 (magnesium alloy), S.A.E. 2330 steel, normalized and also heat treated to about 150,000 psi. tensile strength, N.E. 8630 steel, normalized and also heat treated to about 150,000 psi., 18-8 stainless steel (Type 304), severely cold drawn to 212,000 psi. tensile strength and also annealed at three temperatures, age hardened Stainless W (Type 322), and aluminum bronze. Tables I and II, pages 98 and 99, show the chemical compositions of the materials tested, the specification under which the materials were bought, and the heat treatment. All of the material was in the form of ¾-in. rounds, and most of it was furnished by Wright Field.

Procedure — Standard Charpy specimens with a keyhole notch according to A.S.T.M. specification E23-41T, Fig. 3-B, were used for most of the impact tests. Each specimen was cut from the center of the bar to assure uniformity. The specimens were polished after machining so that all scratches were longitudinal. A number of V-notch specimens were also tested for comparison purposes. One Izod specimen of S.A.E. 2330 was tested at room temperature. Practically all of the impact tests were made on a 220-ft-lb. capacity Riehle machine, using the 220-ft-lb. (18.1 ft. per sec.) initial position. A few tests of the brittle material were made on an Amsler machine using the 35-ft-lb. initial position.

Hardness was determined by a Vickers hardness tester. Cylinders about ½ in. high were cut from the bars, the ends faced in a lathe and then polished with 00 paper. Five impressions with the diamond pyramid were made at regular intervals

Of the authors, M. G. Fontana is professor of metallurgical research and supervisor of metallurgical research, The Ohio State University, and J. L. Zambrow is graduate student and research engineer, The Ohio State University Research Foundation. The assistance of Howard E. Brooks is gratefully acknowledged.

The work reported in this paper was carried out at the Engineering Experiment Station under contract between the Air Materiel Command, Wright Field, Dayton, and The Ohio State University Research Foundation. The cryogenic laboratory at The Ohio State University conveniently furnished the liquid air, nitrogen and hydrogen. The interest of the engineering division of the materials laboratory, Air Materiel Command, Wright Field, in sponsoring this investigation and in granting permission to publish the results is greatly appreciated.

Table I — Composition of the Nonferrous Metals Studied

Material	Specification	Si	Fe	Cu	Mn	Al	Mg	Zn	Cr	Ni	Other
2S aluminum	QQ-A-411b	0.37	0.37	0.15	<0.03	Bal.	<0.03	<0.03		<0.03	0.02 Ti
24S-T aluminum	QQ-A-354	0.16	0.43	3.8 to 4.4	0.6 to 0.9	Bal.	1.2 to 1.7	0.07		<0.05	
75S-T aluminum*	AN-A-9a	0.20	0.45	1.50	0.15	Bal.	2.80	5.70	0.30		0.05 Ti
61S-T aluminum	QQ-A-325	0.5 to 0.7	0.41	0.19 to 0.27	<0.15	Bal.	0.8 to 0.9	0.08	0.19 to 0.28		0.15 Ti
FS-1 magnesium	AN-M-27	<0.01	<0.001		0.49	3.10	Bal.	1.05		<0.001	<0.01 Ca
Aluminum bronze	QQ-B-666	0.02	1.00	Bal.	1.0	9.0				0.50	0.50 Sn

*Procured from stock as "commercial heat treated and aged (at 250° F.)".

along two radii 90° to each other. The average of these 10 values was then taken as the hardness.

Test Conditions and Techniques — Practically all of the materials were tested at five temperatures over the range under investigation, beginning with room temperature. A mixture of acetone and dry ice gave a temperature of −78° C. (−108° F.) The melting point of methylcyclohexane is −127° C. (−197° F.) and this material was partially frozen with liquid air using the cryostat shown in Fig. 1. This same technique was used to obtain −10° C. and −30° C. (14° F. and −22° F.) for some of the tests on the steel specimens, not contained in this report.

For −192° C. (−314° F.) the specimens were cooled in liquid air, and for −253° C. (−423° F.) cooling was accomplished with liquid hydrogen. All specimens were immersed in the coolants for 30 min. prior to the impact test.

The specimens that were tested at the temperature of liquid hydrogen were cemented to the bottom of a paper boat before being immersed. The boat (Fig. 2) served as a container for the liquid hydrogen while the specimen was transferred from the hydrogen container to the testing machine, thus preventing a rise in the temperature. A perforated paper cover was placed over the boat before immersing to keep the hydrogen from bubbling out during the transfer. The strings and paper tab facilitated immersion and withdrawal from the Dewar flask.

After the specimen had soaked for 30 min. the boat was withdrawn and placed on the anvil of the testing machine. As soon as the boat was positioned, the strings were cut and the pendulum released. About 5 sec. was required for these operations. Since the specimen is covered with liquid hydrogen until the instant of breakage there is no opportunity for a change in temperature of the specimen.

The use of the boat undoubtedly increased the absorbed energy during metal fracture, so two boats filled with liquid hydrogen, but with no specimens in them, were tested to determine the correction factor. It was determined to be 0.2 ft-lb.

A similar technique was used for the first work at liquid air temperature. However, tests were made which indicated that there was no perceptible rise in the temperature of the specimen for about 7 sec. after its removal from the cold bath (without the

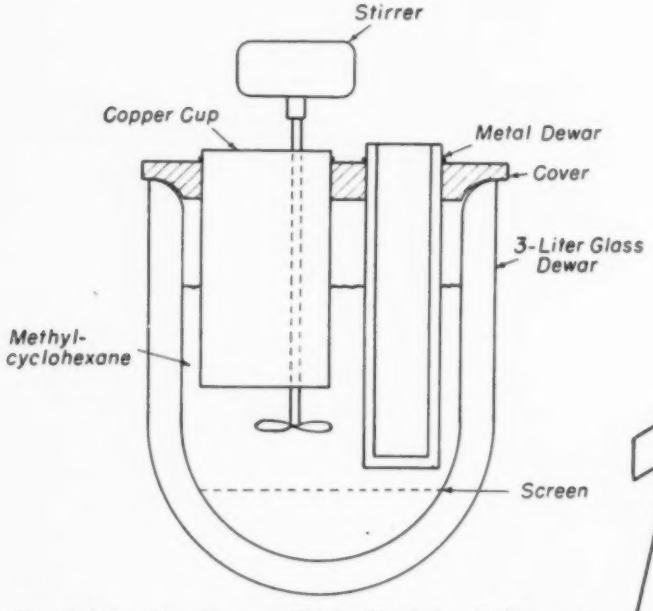


Fig. 1 (above) — Dewar Flask Used for Refrigerating Specimens in Partially Frozen Methylcyclohexane

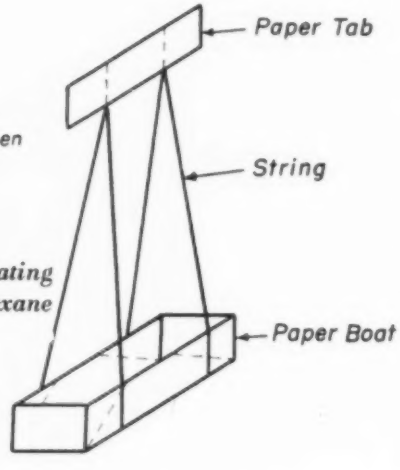


Fig. 2 (right) — Paper Boat for Holding Specimens in Liquid Hydrogen and for Transferring Them to the Impact Testing Machine

Table II — Composition of the Steels Tested

Steel	Specification	C	Mn	P	S	Si	Ni	Cr	Mo	Al	Ti
S.A.E. 2330	AN-QQ-S-689	0.28 to 0.33	0.60 to 0.80	<0.040	<0.040		3.25 to 3.75				
N.E. 8630	AN-S-14a	0.27 to 0.33	0.70 to 0.90	<0.040	<0.040	0.20 to 0.35		0.40 to 0.60	0.15 to 0.25		
Stainless W		0.06	0.45	0.013	0.003	0.53	6.50	17.0		0.12	0.37
Type 304 stainless		0.054	0.49	0.019	0.015	0.42	8.82	18.50			

use of a boat). Since less than 5 sec. was required to position the specimen, all subsequent tests at liquid air or higher temperatures were made without paper boats.

Impressions were made for the hardness tests at room temperature, −78° C. (−108° F.), and −192° C. (−314° F.). In the low-temperature tests, the specimen was placed in the metal-lined wooden dish shown in Fig. 3, and impressions made while the specimens were immersed in a coolant (acetone and dry ice for −78° C., and liquid air for −192° C.), and the impressions were measured after the specimens were brought back to room temperature. Results are summarized in Table III. Tests were also made in which the impressions were made and measured while the specimen was immersed in liquid air. These tests indicated that the increase in diagonal length caused by thermal expansion did not significantly change the hardness number.

Impact Results — Figure 4 summarizes the Charpy impact tests. The materials indicated in this chart are placed from left to right in the order of decreasing impact strength at room temperature of the "as received" material. This chart does not include the results on annealed 18-8 which are shown in Fig. 5. Individual hardnesses for these materials are shown in Table III, page 100.

The 2S aluminum and the low-carbon 18-8 stainless steel exhibit the best and highest impact strengths at these low temperatures with the quench-annealed 18-8 showing the highest values of all the materials tested (Fig. 5).

Aluminum and Aluminum Alloys — The 2S aluminum was apparently in the three-quarters hard condition as indicated by its ultimate strength (19,500 psi.). Annealing the material lowered the Vickers hardness from 44 to 25. The three aluminum alloys were all in the quenched and aged (or "T") condition.

Impact strength of this 2S-¾H alloy increased as the temperature was depressed to −192° C. and decreased at −253° C. These results, however, are not particularly quantitative and not reliable for comparative purposes, because all specimens bent with partial fracture in the impact tests. In fact, it is not strictly correct to report the results for 2S as the "impact strength" of this material, as we are doing in this paper. This point should be kept in mind when studying the data. Perhaps all that should be said is that the 2S-¾H aluminum possesses excellent impact resistance within the temperature range studied.

The 24S-T, 61S-T and 75S-T alloys all behaved alike in that they all failed in a brittle manner and all showed essentially the same impact strength within the temperature range studied. A slight increase in impact strength with decreasing temperature is indicated, with the 61S-T showing slightly higher figures than the other two alloys.

Fig. 3 — Metal Liner Set Into Wooden Block to Hold Refrigerant While Making Hardness Tests

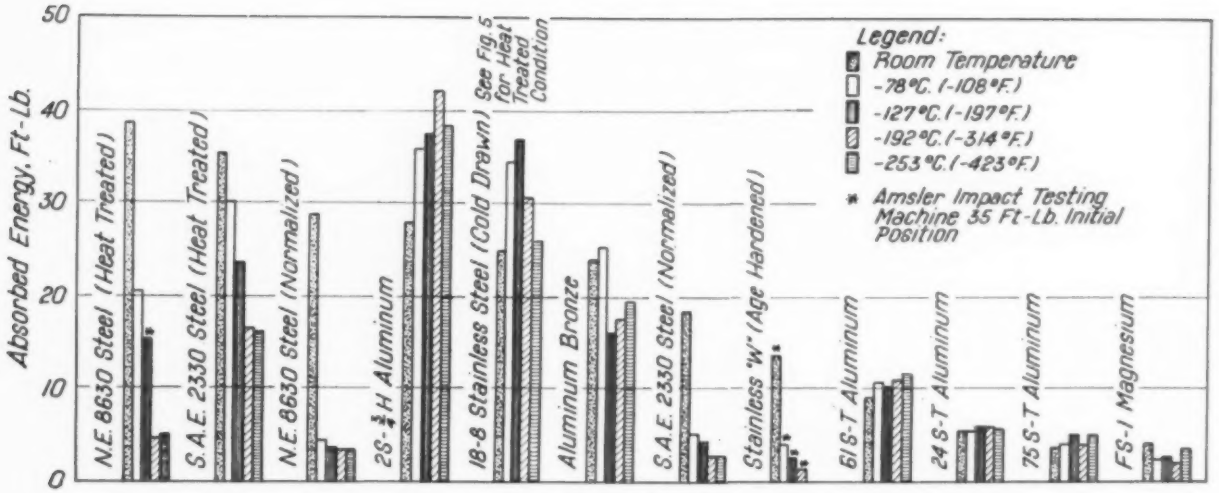


Fig. 4 — Charpy Tests on Aircraft Alloys at Room and Very Low Temperatures

Stainless Steels — Impact values for Type 304, cold drawn to a tensile strength of 212,000 psi., increased slightly at intermediate temperatures, but showed approximately the same value at 20° C. and −253° C. (about 25 ft-lb.). As shown in Fig. 5, the impact strength was considerably increased by fully annealing this alloy (4 hr. at 2000° F. and water quenching). Such annealed material showed decreasing impact strength with decreasing temperature, but the value at −192° C. was still as high as 80 ft-lb. — the highest impact values of all the materials tested. The severely cold worked Type 304 specimens were fractured completely in the impact tests. The fully annealed specimens did not completely fracture at room temperature, but they all broke at the lower temperatures.

Tests on age hardened Stainless W gave an impact value at 70° F. of about 14 ft-lb.; this value dropped to 4 at −78° C. and 2 ft-lb. at −192° C.

Low-Alloy Steels — The results for normalized and also for hardened S.A.E. 2330 and N.E. 8630 steels in the normalized condition dropped sharply as the temperature was decreased to −78° C. showing about 5 ft-lb. or less at −78° C. and about 3 ft-lb. at −253° C. The rate of decrease was more gradual for the 2330.

The superiority of hardened 2330 over hardened 8630, as far as loss in impact values with decreasing temperatures is concerned, is shown by the fact that the 8630 steel showed a practically straight-line drop to about 5 ft-lb. at −192° C. and had this same value at −253° C. The 2330 steel had the same notch toughness at −10° C. as at room temperature, a more gradual drop to −192° C., and the comparatively high value of about 16 ft-lb. at −192° C. and −253° C.

Hardness determinations before and after exposure of the specimens to these low temperatures showed practically identical results (Table III), indicating no permanent changes in the two steels as a result of excessive refrigeration for the short times involved.

Table III — Hardness and Tensile Results

Material	Vickers Pyramid Hardness at			Tensile Strength
	20° C.	−78° C.	−192° C.	(20° C.)
2S aluminum	44	50	60	19,500
24S-T aluminum	143	151	166	69,900
75S-T aluminum	181	193	214	83,900
61S-T aluminum	104	114	130	44,300
FS-1 magnesium	56	62	69	30,000
Aluminum bronze	142	154	168	78,000
S.A.E. 2330 (normalized)	245	286	314	90,000
Heat treated *(a)*	321	359	384	145,000
N.E. 8630 (normalized)	217	252	288	90,000
Heat treated *(b)*	302	327	377	142,000
Stainless W *(c)*	423	460	560	188,000
Type 304 stainless *(d)*	422	480	610	212,000
Quenched 1350° *(e)*	233	310	400	
Quenched 2000° *(f)*	162	205	340	
Quenched 2000° *(g)*	145	215	255	

(a) Oil quenched from 1500° F., drawn at 925.
(b) Oil quenched from 1500° F., drawn at 850.
(c) Air cooled from 1900° F., aged 40 min. at 1000° F.
(d) Cold rolled to 212,000 psi. tensile strength.
(e) Water quenched from 4 hr. at 1350° F.
(f) Water quenched from 15 min. at 2000° F.
(g) Water quenched from 4 hr. at 2000° F.

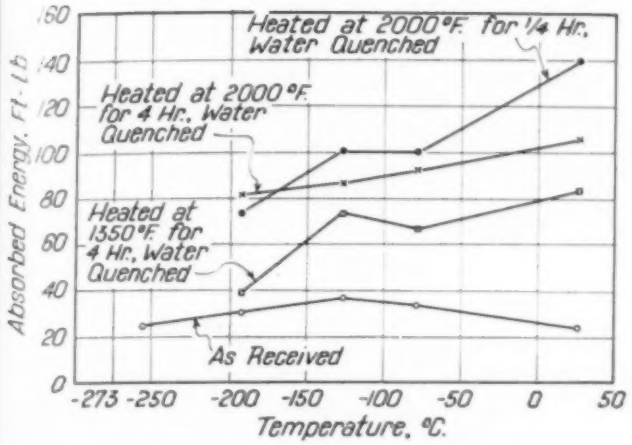


Fig. 5 — Effect of Heat Treating ("Annealing") Cold Drawn Type 304 Stainless Steel (Low-Carbon 18-8) on Charpy Keyhole Tests at Very Low Temperatures

The low-alloy steels are being studied metallographically, and the fracture profiles are under investigation. Interesting results have already been obtained, and this phase of the program will be reported at a later date.

FS-1 Magnesium Alloy showed low impact values over the entire temperature range studied, with all values lying in the range of 2 to 4 ft-lb.

Aluminum Bronze — The results for the aluminum bronze are a "shotgun" scattering. The blocks for Fig. 4 are merely made to the average of the values obtained at each temperature. Metallographic examination showed a coarse plate-like structure; the material was in the cast condition. Profile studies showed that the specimens exhibiting high impact values fractured largely through the plates of alpha bronze, whereas those showing low values fractured largely through the dark-etching matrix material. The impact value was also dependent on whether or not the fracture occurred parallel to or at right angles to the plates. Results would have been more consistent on wrought material.

Hardness — All of the materials investigated showed an increase in hardness with a decrease in temperature (see Table III). Hardnesses were determined at only the three temperatures noted. Increasing the hardness by lowering the temperature resulted in little change in impact values for 24S-T, 61S-T, 75S-T, FS-1 and cold drawn Type 304 stainless. Increased hardness because of lower temperatures showed decreased impact values for S.A.E. 2330, N.E. 8630, annealed Type 304 and Stainless W. For annealed Type 304 the impact values increased with decreasing hardness when the temperature of annealing was increased and also when the hardness of the cold drawn material was decreased because of heat treatment.

Correspondence

From a French Friend

TOULOUSE, H-G., FRANCE

To the Editor of METAL PROGRESS:

Today there arrived at Le Havre the ship carrying the supplies collected by the "Friendship Train" provided by the generosity of your compatriots. Such a gesture does not leave the French people indifferent, and therefore I consider it my simple duty to send you this expression of my gratitude and thanks, which I address at the same time to all of your fellow citizens.

I hope you will excuse me for sending you these few words, which only poorly convey my sentiments as well as those of my family, but you are the only citizen of the United States with whom I am acquainted. You will probably remember that about February 1946 you solicited your American readers to send food packages to members of the Society of Engineers at Toulouse, and this is how I came in contact with you.

With renewed thanks, believe, dear Mr. Thum, in the expression of my affectionate sympathy.

RENÉ BISCANS

Hexagonal Slip in Beryllium Crystal

NEW YORK CITY

To the Readers of METAL PROGRESS:

Lester Tarnopol's photograph of a Brinell impression in a beryllium crystal which appeared in the September issue of *Metal Progress* (p. 391) is interesting evidence for speculation, but I wonder if his appraisal of the deforming mechanism is correct. To quote Barrett★: "When a stress is applied to a crystal, it should cause slip, twinning, or cleavage, depending on whether the resolved stress on the slip plane in the slip direction, or on the twinning plane in twinning direction, or normal to the cleavage plane, exceeds the critical value for the process concerned." The symmetry of the markings in Tarnopol's photograph indicates to me that the surface in view is the basal plane of the crystal. The (0001) slip,

★"Structure of Metals", McGraw-Hill, 1943, p. 322.

therefore, could not intersect the surface and the markings shown must be other planes than the (0001).

A highly suspicious set of planes would be the {10$\bar{1}$2}, that is, the customary twinning plane for close-packed hexagonal crystals. The stresses created by the indentation are quite complex but high shear stress values certainly should be resolved parallel to the twinning plane.

The straight cracks are apparently cleavages on the prism planes of Type I, that is, {1$\bar{1}$00}. The jagged crack is merely a mixture of two alternative cleavages of the {1$\bar{1}$00} type.

There was no doubt some slip on the (0001) plane, but the slip markings would have to appear around the surface of the indentation where they naturally were obliterated.

JOHN P. NIELSEN
Assoc. Prof. of Metal Science
New York University

Fundamental Considerations Regarding Friction

MUNICH, GERMANY

To the Readers of METAL PROGRESS:

It is truly said that machines seldom break; most machines either wear out or rust out. You in America have always given much attention to the study of corrosion; the other major cause of mechanical loss — friction — has received far less study. Perhaps, then, it would be well to outline the conclusions reached after much investigation.

Friction may be defined as the loss of energy due to permanent deformations and local ruptures within the opposing parts. (It is doubtful if molecular adhesion or welding of clean metal surfaces — the stick-slip cycles at a tool face — may properly be included in the foregoing definition.)

Permanent deformation associated with friction may be either large in scale (macro) or small in scale (micro). The first is generated by the change in the shape of the contacting bodies under pressure. A wheel is somewhat flattened; the rail receives a slightly curving indentation. If the repetitive strains are above the fatigue limit, they are no longer elastically recovered; cracks at about 45° to the surface may appear. However, if the material has a low elastic limit, the metal will "flow", as does biscuit dough when it is rolled; its particles change their position to oppose a greater surface to the pressure. If shocks occur, such flow is more accentuated. If a steel has a low elastic limit, its carbon content, hardness, and a relatively high "yield" or "proof" stress, will not guarantee that it will not flow, in the above sense. Sorbitic or fine pearlitic steels have high elastic limits and great internal energy, and consequently a correspondingly high resistance to flow.

The second cause of friction is the microdeformation of the surface irregularities or asperities. (Every surface, of course, is *somewhat* rough.) Any asperity higher than average which gets into a depression in the opposing contact body is sheared off. However, such shear is not the main cause of microfriction. The latter is generated by *compression* deformations between the tops of the opposing irregularities — ridge against ridge; peak against peak. If the asperities have an equal height, if their tops are flat, if their number in actual contact is great, if, in short, the surfaces are well finished, the specific pressure on the tops is small, the deformations are low, as is also the friction.

Of course, cracks and flow may occur at the microdeformations as well as at the macrodeformations. If hard particles of cementite break off they will scratch the opposing surfaces. If, on the other hand, the troughs between microprojections are filled with particles that can transmit pressure, the actual contact surface is greater and the average deformation of the asperities is smaller. The favorable action of evenly distributed graphite in gray cast iron (after the first stage of wear), and of the gases occluded on metallic surfaces, may be explained by the above propositions. On the other hand, heat generated by undue friction has been known to cause damaging phase changes in the journal surfaces.

A phenomenon observed in rolling mills is that friction is diminished as the speed of the moving part increases. This is logical, because the greater the speed of deformation the higher the load to produce it. Increasing the speed of a shaft, for example, is equivalent to raising the resistance of the journals.

When lubricant separates the contact surfaces, the friction theoretically is between the molecules of the fluid. In any event, the pressure between asperities on the journal surfaces may be transmitted by a thin oil film, and the asperities wear down. Likewise, the measured friction of well lubricated bearings is greater than predicted by hydrodynamical theory.

Finally, it may be remarked that ideal rolling friction does not actually exist, as it requires nothing but point-to-point or element-to-element contact between the surfaces, yet both surfaces are actually deformed enough to give more bearing than this. Furthermore, some slipping always occurs.

A. MITINSKY
Professor
World Y.M.C.A. University for Displaced Persons

8 DRAWS-NO ANNEALS-MAKE MOTOR CASE

SEVERAL different types of Revere Metals go into the making of the famous Telechron Electric Clocks. They include copper, brass, and commercial bronze or "gilding metal." Each type is most carefully selected to match the strict requirements of fabrication and operation. In making those selections, and in working out the most favorable manufacturing methods, Revere and Telechron collaborated closely and effectively.

Take the motor case, which involves a deep draw in a relatively small part. The metal must not only be suited for this operation, but must be non-magnetic, since the lines of force from the motor's electromagnet must penetrate the case in order to operate the motor. Naturally, a copper alloy was indicated—but *which?* Telechron had eyelet-type press tools designed and built for the eight drawing operations. The Revere Technical Advisory Service was called in when unexpected production difficulties arose. Through a mutual study, these difficulties were entirely eliminated by specifying Revere Commercial Bronze, 95%, and by making other changes. No anneals are now required to produce the case. Production was stepped up, rejects reduced, marked economies obtained . . . Revere will gladly cooperate with any manufacturer faced with problems in the non-ferrous metals.

• • •

REVERE PRODUCTS: *Copper and Copper Alloys:* Sheet and Plate, Roll and Strip, Rod and Bar, Tube and Pipe, Extruded Shapes, Forgings. *Aluminum Alloys:* Tube, Extruded Shapes, Forgings. *Magnesium Alloys:* Sheet and Plate, Rod and Bar, Tube, Extruded Shapes, Forgings. *Steel:* Electric Welded Steel Tube.

REVERE

COPPER AND BRASS INCORPORATED

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Sales Offices in Principal Cities, Distributors Everywhere

Telechron Kitchen Clock, Buffet Model, made by Telechron Inc., Ashland, Mass., motor, and progressive steps in manufacture of the motor case.

Personals

Leon F. Marsh is a member of the firm of Graydon Smith & Co., Boston, consulting mechanical and electrical engineers.

Formerly with Johnston & Jennings, Cleveland, **Hollis Walker** has been appointed superintendent of the forge division of Kraeuter & Co., Irvington, N. J.

John R. Wolfe is now associated with the Corduan Mfg. Co. of Chicago as superintendent.

Paul E. Schweizer, formerly chief metallurgist for Bulova Watch Co., has organized Testing & Consulting Co., Inc., offering a consulting service in mechanical and metallurgical engineering.

Resigning as manager of sales, Christy Park products division, National Tube Co., **H. E. Passmore** now represents Taylor Wharton Iron & Steel Co., Easton, Pa., and Bart Mfg. Co., Belleville, N. J.

H. A. Brackmann is now sales representative of Vulcan Crucible Steel Co. in the Detroit area where he will sell toolsteels.

J. Dewton is at present sales engineer for the Kelley-Koett Mfg. Co., Covington, Ky., in the Manhattan area.

Herbert J. Gough, the English authority on strength of materials, was recently awarded the Medal of Freedom of the United States by President Truman for his war work as controller of research and development for the British Ministry of Supply. Many Americans will recall Dr. Gough's prewar visits to America when he was superintendent of the engineering department of the National Physical Laboratory.

Robert L. Ziegfeld has been promoted from acting secretary to secretary of Lead Industries Assoc.

Carl A. Liedholm, who has served as chief engineering metallurgist of Curtiss-Wright Corp.'s propeller division since early in World War II when the plant was built in Caldwell, N. J., has resigned to become quality manager of the Piasecki Helicopter Corp. in Morton, Pa. He is succeeded at Curtiss-Wright by **B. J. DeSimone**, who has been assistant metallurgist for the firm for seven years.

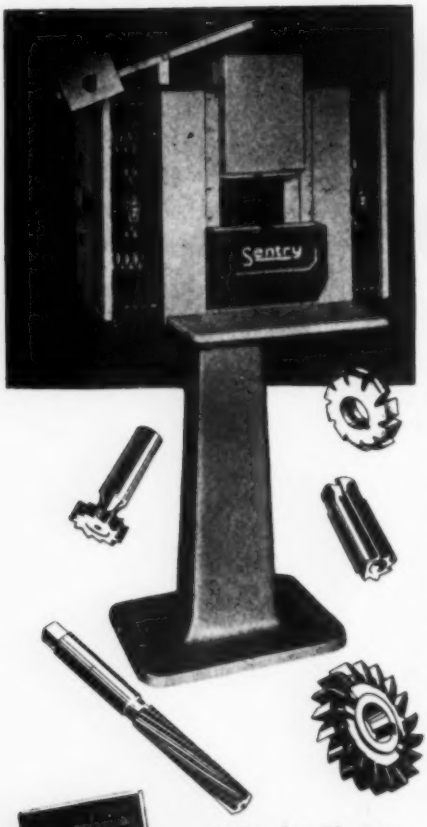
Herbert Dobkin, a member of the subcommittee on Relief of Residual Stresses for the forthcoming A.S.M. Handbook, has recently left the M. W. Kellogg Co. to become a partner in Ace Heat Treating Corp., Elizabeth, N. J.

William F. Collins, consulting engineer for many midwestern industries for the past 20 years, is leaving St. Louis where he has been engaged by Socony-Vacuum Oil Co. and is establishing a new office in Los Angeles shortly after the first of 1948.

W. E. Day, who has been associated with Mack Trucks, Inc., for the past 35 years, has been appointed director of research of the company; his former post was chief metallurgist and general foundry superintendent. Mr. Day has been responsible for the organization of the Mack laboratory, and his work has led to the development of several new alloys including Mack's brake-drum iron.

Leaving Electro Motive Division of General Motors Corp., **W. Gerard Rauch** is at present on the metallurgical staff of the Argonne National Laboratory, Chicago, of the Atomic Energy Commission.

For { TOOL ROOM or PRODUCTION LINE



SENTRY ELECTRIC FURNACES

Sentry High Speed Steel Hardening Furnaces are flexible, quick to heat to operating temperature and noted for their reliability and operating economy. They are equally adaptable to the production line and to tool room use.

Sentry Furnaces provide a correct application of the Sentry Diamond Block Method—a scientific control for maintaining a neutral atmosphere. They are clean—no fumes—no wasted fuel. Work is scale-free, with no decarburization—no reduction in size. One operator can tend several furnaces.

There's a Sentry Furnace to meet your particular requirements.

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ELECTRIC FURNACES BY SENTRY: HIGH SPEED STEEL FURNACES
MEDIUM & HIGH TEMP. INDUSTRIAL • CRUCIBLE • POT • HIGH TEMP. TUBE

Lockheed P-80 Shooting Star.
Photo courtesy of Lockheed Aircraft Corporation

jet propulsion

demands the best

that's why ACCOLOY Stainless Steel Castings *are specified*

Since the inception of the *Jet Engine Program*, Alloy Casting Company has had the privilege of working with several jet engine manufacturers in the development of High Temperature materials to withstand the rigid requirements of cyclic heating and cooling. Much of this development work still remains secretive.

The photograph at right illustrates a special *Stainless Steel* casting spun at 2 *miles per minute* in a metal die. Parts machined from this tube had to withstand the most rigid specifications ever set up for a casting. The shroud rings are *centrifugally* cast to tolerances heretofore unheard of in the casting industry.

These jet propulsion castings constitute just one of the many phases of our development work. Consult us on your *heat* and *corrosion* problems.

HEAT RESISTANT CASTINGS
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STAINLESS STEEL CASTINGS

Next time call an ACCOLOY Engineer

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Count on **G. O. CARLSON, Inc.**

for **STAINLESS RING FLANGES**

Produced to Chemical Industry Standards In All Generally Used Analyses

Bevelled Flanges—Save machining and handling by specifying flanges bevelled ready for welding.

Threaded Flanges—Accurate threading on the I. D. and bolt holes if desired.

Stub End and Ring Blanks—Cut to size for fabricating into necks, nozzles, washers, gaskets, etc.

Take advantage of Carlson's specialized experience in producing and cutting stainless plate —

Send blueprints and specifications today for prices on stainless ring flanges in any size, or for any other irregular shapes in stainless plate up to the world's largest.

G. O. CARLSON, INC.

Stainless Steels Exclusively

THORNDALE, PA.

Personals

John P. Walsted has left the Navy Proving Ground to accept a position as physical metallurgist at the U. S. Bureau of Mines.

On his graduation from Ohio State University, **Harold Meese** has joined the Wheeling Steel Corp. in Steubenville, Ohio, as senior metallurgist of the cold strip mill.

D. G. Murray has relinquished proprietorship of the D. G. Murray Mfg. Co. to become a partner in Alexander & Murray, consulting production engineers, Sydney, N.S.W., Australia, and to take over the managing directorship of G.H.M. Engineering Pty., Ltd., Sydney.

R. S. Zeno has joined the staff of the research laboratory of the General Electric Co., Schenectady, after receiving his M.S. in metallurgy from Pennsylvania State College.

On graduating from the University of Minnesota, **Charles J. Williams** has joined the research staff at Battelle Memorial Institute, Columbus, Ohio.

Formerly metallographer of the aircraft engine division of Packard Motor Car Co., **H. W. Hanes** is now metallurgist of the National Pressure Cooker Co., Eau Claire, Wis.

L. P. Mendoza is now assistant purchasing agent of Stone & Webster Engineering Corp., Schenectady.

Anderson Oil Co. of Portland, Conn., announces that **Clyde A. Sluhan**, for several years its Connecticut salesman, has been appointed the manager of industrial sales.

Victor Brown, director of research and metallurgy of Kropp Forge Co., Chicago, has been elected a director of the company. Mr. Brown has been at Kropp Forge Co. for the past five years, having been previously associated with the Republic Steel Corp.

Atlas Steels, Ltd., Welland, Ont., announces the election of **Arthur G. Lambert** as vice-president and manager of the export division. Mr. Lambert joined the company in 1940 as export manager.

Oneal V. Gagner, formerly superintendent of Loring Coes Co., is now associated with the National Knife Co., York, Pa., as supervisory engineer.

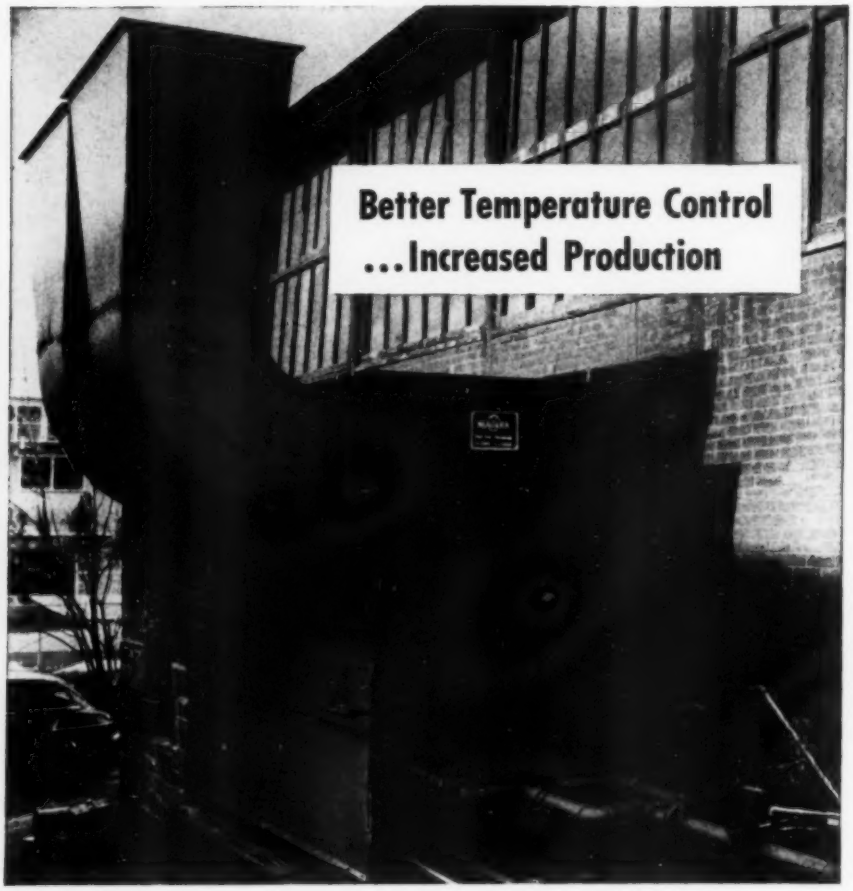
THE GENERAL ALLOYS COMPANY

extends to their business associates

and many friends and patrons

BEST WISHES FOR
A HAPPY AND PROSPEROUS
NEW YEAR

H. H. HARRIS, *President*



● Where the cooling of liquids or gases is part of your process, the NIAGARA AERO HEAT EXCHANGER will save over 95% of the water you use for cooling.

An even greater advantage is the closer control of temperature which results in improved quality, reduced loss in rejections, and the speeding up of production performance.

Applications include cooling jacket water for process equipment or engines; cooling cutting oils, lubricants, hydraulic equipment; quenching baths of water, oils or solutions; electronic sets, transformers; controlled atmospheric processes, compressed air or gas cooling.

Write for the story of examples in your particular process. Ask for Bulletin 96-MP.

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INDUSTRIAL COOLING HEATING • DRYING

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Personals

Ralph N. Schaper has left Westlectric Castings, Inc., Los Angeles, and is now associated with Marion Malleable Iron Works, Marion, Ind.

Jack L. H. Everitt has recently joined the research engineering department of Massey-Harris Co., Ltd., of Toronto, Canada, in the capacity of engine designer.

Joslyn Mfg. and Supply Co. announces that **F. B. Davis** will be its sales representative in New York.

J. Mathes, formerly superintendent of sales service of the National Tube Co.'s Ellwood City, Pa., plant, is now president of the Erie Steel Treating & Metallurgical Co., Erie, Pa.

Michael Kocsuta has been appointed general manager of Scranton pump division, Condenser Service & Engineering Co., Scranton, Pa.

G. H. Brundage, Jr., was recently transferred from the Waterbury, Conn., plant of the U. S. Time Corp. to the Little Rock, Ark., plant.

Formerly with the magnesium division of The Dow Chemical Co., **A. M. Lennie** has accepted a position as industrial consultant for the University of Wichita Foundation for Industrial Research in Wichita, Kan.

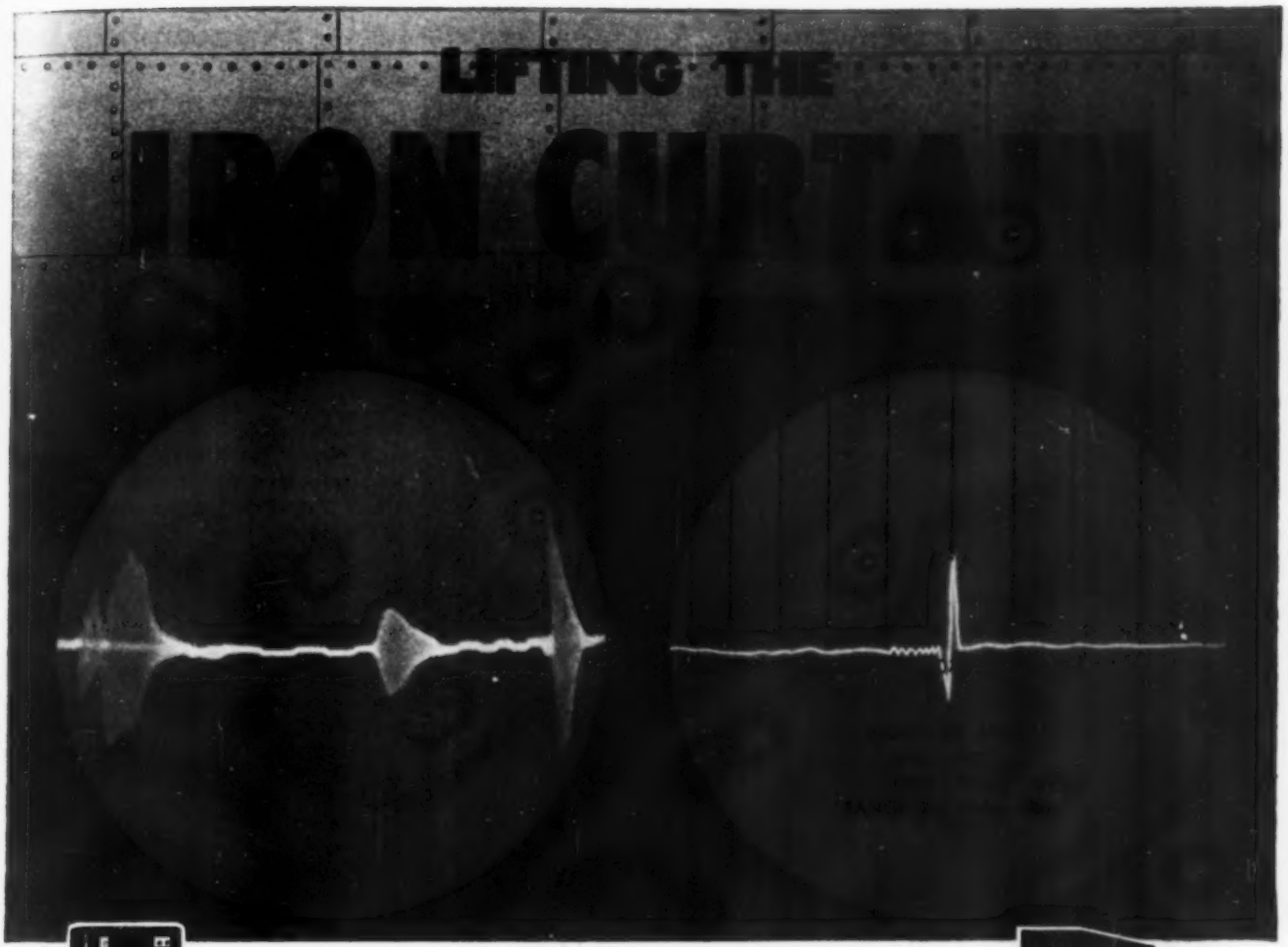
Chester R. Wilson is now associated with the High Standard Mfg. Corp. of Connecticut as assistant metallurgist.

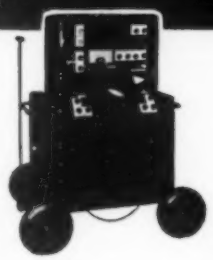
After the completion of requirements for his M.S. degree at Missouri School of Mines and Metallurgy, **Roger D. Moeller** was appointed metallurgist on the staff of the Sharples Corp. research laboratories, Philadelphia, Pa.

R. E. Olds resigned his position as alloy product manager of the U. S. Steel Export Co. to assume the vice-presidency of Leroco Associates, Inc., of New York and Los Angeles.

C. W. Smith, formerly field testing engineer for Wilson Mechanical Instrument Co. in the Michigan territory, has become chief development engineer for the company at the factory in Bridgeport, Conn.

F. C. Bethancourt has recently become associated with the J. B. Beaird Co., Inc., Shreveport, La., as engineer.





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THE SUPERSONIC REFLECTOSCOPE

(1) *Locates smaller defects — penetrates deeper* into metals than any other non-destructive testing device.

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(1) *Measures thickness of metals* and other materials from .025 in. to 4 in.

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SP-108

Month after month, top-quality machine-tools work around the clock — without the profit-killing penalty of excessive maintenance downtime. Your best assurance of this dependability is Ampco Metal in critical machine-tool parts like the shifter fork shown here.
Death on downtime—
durable Ampco Metal
parts keep machines at work

This wear-resistant aluminum bronze reduces maintenance time and replacement costs . . .

There's no ceiling on the cost of expensive downtime, but there's good insurance against it—durable Ampco Metal in critical machine-tool parts. The extra wear-resistance of this modern aluminum bronze means longer and better service—lower maintenance costs.

Ampco Metal parts are a mark of quality to look for when you buy new equipment. Replace worn parts in your present machines with Ampco Metal to reduce replacement frequency in the future and slash your service and maintenance costs to a new low.

Ampco Metal can be produced by centrifugal- and sand-casting, extrusion, or forging processes according to your requirements. Let your nearby Ampco engineer help you select the proper grade for your needs, from the seven standard grades and several modifications available. For complete information, write for Bulletin 71.

AD-32A

Ampco Metal has 7 outstanding performance advantages

Excellent bearing qualities • High strength-weight ratio • High compressive strength • High impact and fatigue values • Corrosion resistance • Wear resistance • Efficiency at extreme temperatures.

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Personals

R. F. Haskins, formerly associated with Nash-Kelvinator Corp., is now chief metallurgist of Blood Brother's Machine Co., division of Standard Steel Spring Co., Allegan, Mich.

Orville J. Barnett has been transferred from division engineer in the electrode division to district sales manager, welding division of Metal & Thermit Corp., Newark, N. J.

Nelson F. Murphy, formerly director of engineering and development for Bristol Laboratories and assistant professor of chemical engineering at Syracuse University, has been appointed research professor in chemical engineering at Virginia Polytechnic Institute, Blacksburg, Va.

Formerly process metallurgist in the chemical department, metallurgical division, General Electric Co., **Robert J. Breska** is now foundry superintendent at Thomas & Skinner Steel Products Co., Indianapolis, Ind.

Lloyd B. Kramer has recently joined the materials engineering department of the East Pittsburgh plant of Westinghouse Electric Co.; he was previously with the Biad Powder Metallurgy Co.

E. Ineson has recently resigned his post as chief research metallurgist to Messrs. David Brown & Sons (Huddersfield), Ltd., in order to take up employment with the British Iron & Steel Research Association at their head office in Park Lane, London, England. He will work in the metallurgy division surveying problems connected with the properties and utilization of carbon and alloy steels.

Metlab Co., Philadelphia, announces the appointment of **A. R. Fairchild** to the position of plant superintendent. Mr. Fairchild was previously with the New York Shipbuilding Co.

Wm. B. Beer has recently accepted a position in the contracting division of Dravo Corp., Pittsburgh.

Kermit V. Smith is now employed at the Gary works of Carnegie-Illinois Steel Corp.

On graduation from Cornell University this past June, **Eugene S. Carlson** joined the Worthington Pump Corp., Harrison, N. J., as student engineer.

Personals

O. H. Kuhlke is now with General American Transportation Corp. as technical instructor.

Herbert B. Robinson has been appointed assistant to the director of the service and development laboratories of the A. O. Smith Corp., Los Angeles, Calif.

V. J. Gauthier has been appointed assistant professor in the mechanical engineering department at New York University, where he will be in charge of the machine tool laboratory and the metal cutting research.

Walton R. Yerger, formerly with the Sikorsky Div., United Aircraft Corp., is now the metallurgical engineer for American Screw Co., Providence, R. I.

James H. Hinman has been appointed assistant technical adviser and transferred from the Rome division to the New Bedford division of Revere Copper and Brass, Inc.

H. J. Brenneke, formerly assistant professor of engineering shop practice at New York University, is now associated with the Wadhams division of the Socony-Vacuum Oil Co. as a metals processing engineer.

Dan E. de Leon has been transferred from the Corps of Engineers' Little Rock engineer district to the U. S. engineer district at New Orleans, La.

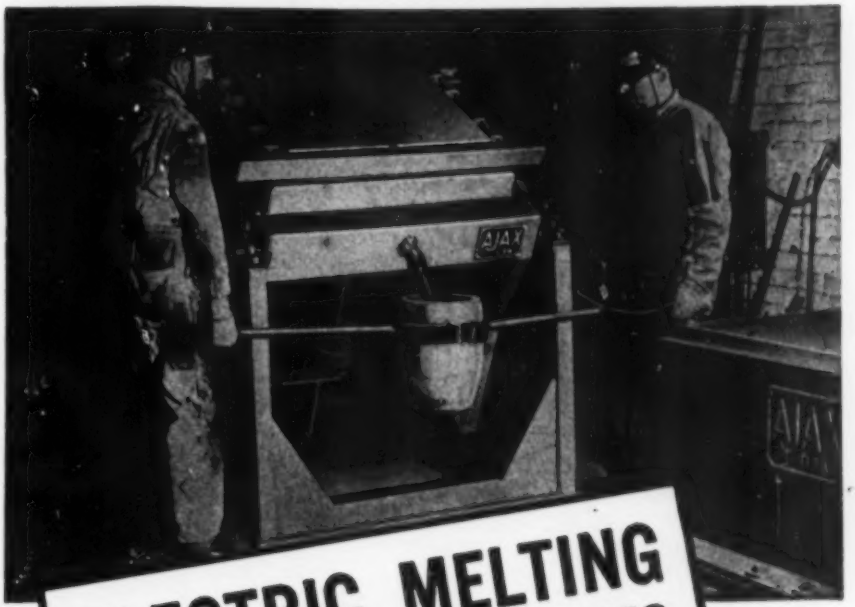
W. V. Wilcox has returned to Senter Tool Service, Portland, Ore.

J. Edward Oetjen has recently become design engineer in the mechanical engineering division of the H. K. Ferguson Co., Cincinnati, Ohio.

Formerly development engineer with Reynolds Metals Co., John D. Olson is now head of distributor sales in northern Ohio for Manning, Maxwell and Moore, Inc.

The Carpenter Steel Co., Alloy Tube Div., Union, N. J., announces the appointment of John A. Deitrich as manager of the division.

Climax Molybdenum Co. announces the appointment of Norman L. Deuble to its metallurgical engineering staff. Mr. Deuble has been with the M. W. Kellogg Co. for the past four years in charge of special processes and of the work in the high temperature laboratory.



ELECTRIC MELTING of ALUMINUM ALLOYS

No Longer a Luxury

Aluminum alloy iron-core induction melting furnaces, the first of this kind capable of continuous operation, have been developed at Ajax's Experimental Foundry (see photo upper right). Simplified cleaning methods and improved design of melting channels have resulted in increased lining life and reduced maintenance cost.

Job of melting 300 pounds per hour requires 60 kw. unit (see photo above) occupying about 4' x 4' x 4' space, requiring no foundations and provided with a self-contained internally wired control cubicle, including potentiometer type temperature controller. Operating cost from 40 to 70 cents per hour, with maintenance items almost negligible.

Another unit of 20 kw. capacity is finding wide acceptance as holding furnace in die casting and permanent mold work. Space required is about 3' x 3' x 3', no foundations, self-contained control cubicle. Operating cost from 8 to 12 cents per hour. Metal charge of crucible is 300 pounds.

X-ray investigation carried out on metal processed in Ajax induction furnace proves that accurate (free of time lag) temperature control, typical of these furnaces, allows casting consistently at lowest and most adequate temperatures necessary for sound castings, all of which results in considerable reduction of rejects.

AJAX ENGINEERING CORPORATION
TRENTON 7, N. J.

AJAX TAMA-WYATT INDUCTION MELTING FURNACE

Associate Companies: AJAX METAL COMPANY, Non Ferrous Ingot Metals and Alloys for Foundry Use. AJAX ELECTROTHERMIC CORP., Ajax Northrup High Frequency Induction Furnaces. AJAX ELECTRIC CO., INC., The Ajax Hultgren Electric Salt Bath Furnace. AJAX ELECTRIC FURNACE CORP., Ajax Wyatt Induction Furnaces for Melting.

The cartridge weighs hundreds of pounds. The welding flanges weigh only a few pounds each.

Hardly a day goes by but such "contrasts in castings" show up in our foundry. With a battery of modern electric furnaces and the best obtainable foundry equipment, we are in position to turn out static castings up to 6 tons and centrifugal castings 24 inches O.D. and up to 15 feet long, depending upon the diameter.

If you want high alloy castings backed by experience, and produced under the best of conditions, come to Duraloy.

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Los Angeles & San Francisco: KILSBY & HARMON

Chicago & Detroit: F. B. CORNELL & ASSOCIATES

Houston • Dallas • Tulsa • New Orleans • Kansas City

1-DU-2

Personals

John S. Peake left the magnesium division of The Dow Chemical Co. and is now associate professor in the chemistry department at Indiana University, Bloomington, Ind.

Albert J. Phillips, superintendent of the research department of American Smelting & Refining Co., Barber, N. J., has been elected to be one of the new directors of the American Institute of Mining and Metallurgical Engineers.

Wear Measurement

AN extremely accurate method of locally measuring the extent of wear of machinery surfaces has been devised by S. A. McKee and H. C. Dickinson at the National Bureau of Standards. The device consists simply of an apparatus for producing a diamond shaped impression similar to that used in the Knoop tester for measuring hardness. By means of a proper fixture a diamond point is forced into the surface to a predetermined depth. By measuring the length of the impression before and after, increments of wear as small as a hundredth of a thousandth inch (0.00001 in.) can be detected. Typical impressions are originally about 0.001 in. deep with a long axis of about 0.035 in.

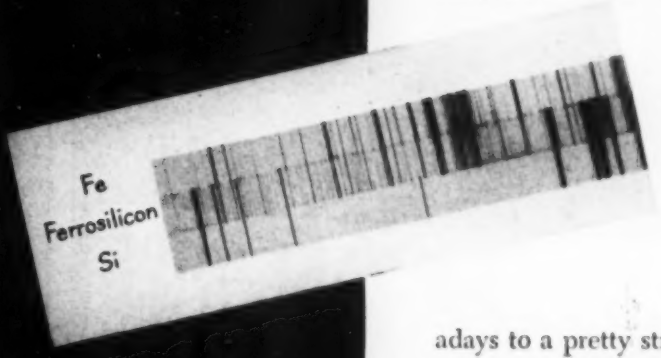
Previous test methods include measurement of dimensional change, weight loss, and determination of the amount of worn material found in the lubricant. Their chief limitations are that extreme accuracy is not obtainable in measuring the changes in dimensions, and while the weight loss indicates total wear, it gives no indication of where the wear occurs.

The McKee gage was developed primarily to measure the wear on cylinder walls and pistons of radial aircraft engines. Viewing and measuring apparatus consists of a conventional microscope and eyepiece scale, modified by the addition of two right-angle prisms when viewing the inside of cylinders. Locating pins are so arranged that a mark made at a given pin-setting will fall within the field of vision. The marks are placed with the *(Cont. on p. 114)*

This light slashes your analytical costs

. . . the quickest way to make *sure* what's in a material is to analyze the light it emits as a hot gas

Spectrochemically, 14 elements can be determined in ferro-silicon at the rate of three samples an hour—a job that takes 100 man-hours per sample by "wet" methods.



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Your sample can be very small. It may be a little disk of metal that you spark with AC . . . a bit of powder that you put into a carbon arc. The characteristic wavelengths that each element in it contributes to the light produced, are sorted out by the spectrograph which images them on a photographic film or plate. Into your files goes a permanent, compact record of *the elements in your sample, whether expected or not.* Months or years later it is still available to settle questions—objectively.

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Wear Measurement

(Starts on p. 112) long axis perpendicular to the axis of the cylinder.

Experience shows that marks in engine cylinders retain their shape sufficiently to provide reasonably accurate wear measurements. Results are not satisfactory after the marks have been worn to about one fourth of the original length. Greater accuracy is therefore obtained by adjusting the duration of the test to result in less than this amount of wear. The points on fresh impressions are sharp and the lengths can be accurately determined; however, after wear occurs the ends of the marks are somewhat blunted and it is necessary to estimate the position of the point. Under favorable conditions cylinder wear can be determined with an over-all accuracy of ±0.00002 in.

Typical wear tests on aircraft cylinders reveal unsymmetrical wear with respect to the axis. This would be very difficult to determine by any previous method. The data were obtained from 24 impressions spaced uniformly around each cylinder at four different levels. Further tests were made with the McKee gage on automobile engine cylinders under controlled operating conditions. The engines were operated for 144 hr. (equivalent to 3000 miles of normal operation). The cycle consisted of 20 min. of operation with a 10-min. stop for cooling. The tests revealed an average cylinder wear of 0.00002 in. per 1000 miles of operation. The results further showed that a greater amount of wear resulted when the engine was started at a low temperature than at a high temperature (120° F.). The data suggest that corrosion may be responsible for a major part of the wear in normal engine operation.

The McKee gage is not affected by distortion during operation, whereas measurements of diameter change do not differentiate between wear and distortion. The McKee gage marks can be placed at any number of points on the surface and in this manner indicate wear at any point on the surface regardless of the factors of distortion or nonuniform wear. The indentation principle appears to have other practical advantages such as, for instance, indicating when production dies are worn beyond specified tolerances.

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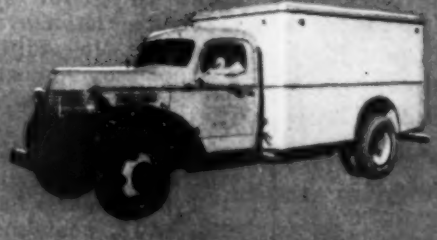
SOLUTION—Magnesium reduced weight by 20 per cent. A single upholstered seat weighs only 29 pounds. Ease of extruding Magnesium made possible the use of special shapes thus eliminating fabricating costs.



PROBLEM—Increase truck capacity, cut maintenance costs.
SOLUTION—a Magnesium body weighing only 1,700 pounds—a saving of 2,000 pounds over steel. Magnesium sheet and extruded sections were used. Service reports show that these bodies stand up under hard use.

PROBLEM—produce a light-weight chair for use in railroad dining cars. Must be simple in design and construction.
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Strength of Mg-Zr Alloys*

GREAT SUCCESS has been achieved in developing magnesium alloys with materially improved properties, primarily through the use of zirconium. That the problem is beset with difficulties is clearly demonstrated by the fact that although many high-strength magnesium alloys have been proposed and patented in the past 20 years, none have prospered, with the result that until the advent of the zirconium alloys, the alloy systems in general use remained the magnesium-aluminum-zinc series or the magnesium-manganese series. The history of the magnesium-zirconium series started in 1938 in Germany when I. G. Farbenindustrie discovered that zirconium, especially in conjunction with a third element such as zinc, is an intensive grain refiner in magnesium. At the same time so many difficulties were encountered in introducing zirconium into the melt that further work was dropped. Magnesium Elektron, Ltd., of England carried on, however, finally developing the method of introducing properly prepared zirconium fluoride or fluozirconate into magnesium alloys free from flux inclusions and other impurities.

The fine grain developed in zirconium-zinc-magnesium alloys is reflected in the substantial improvement in proof stress, creep resistance, ultimate strength and elongation. In addition, they yield a complex oxide coat which makes this series of alloys more corrosion resistant than the best of those using normal purity. The series is especially proof against pitting.

Typical figures for the sand cast alloy, Z5Z, containing 4.5% zinc, 0.7% zirconium, balance magnesium, are 18,000 to 19,000 psi. proof stress at 0.1% strain, 35,000 to 37,000 psi. ultimate tensile strength and 8.0 to 10.0% elongation in 2 in. This alloy may be heat treated (180° C. or 355° F. for 24 hr.) to give the following properties: 21,000 to 22,500 psi. proof stress at 0.1% strain, 36,000 to 40,000 psi. ultimate tensile strength and 7.0 to 9.0% elongation. *(Cont. on p. 118)*

*Abstracted from "Outstanding Properties of the Magnesium-Zirconium Alloys", by C. J. P. Ball, *Metallurgia*, Jan. 1947, p. 125-129; Feb. 1947, p. 211-214.

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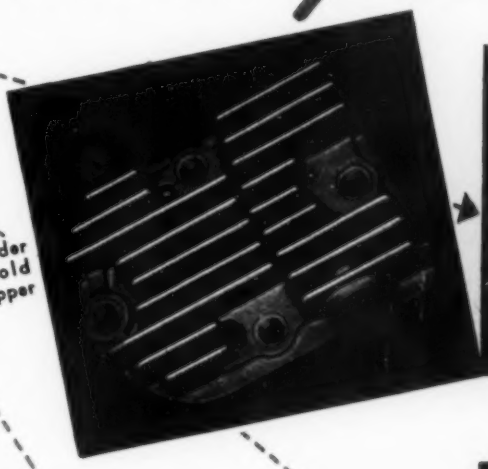
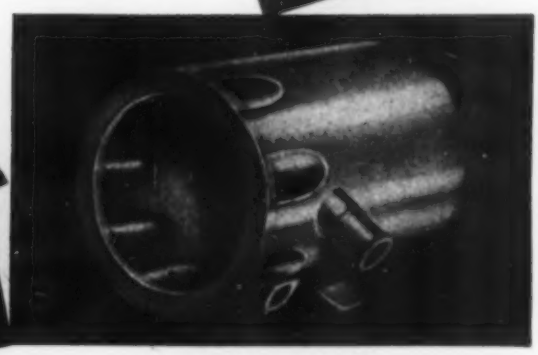


Gasoline Engine Cylinder Head • Permanent Mold Casting • Aluminum - Copper - Silicon Alloy



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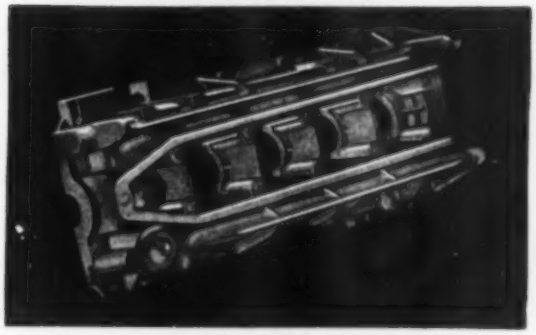

Automobile Engine Crankcase
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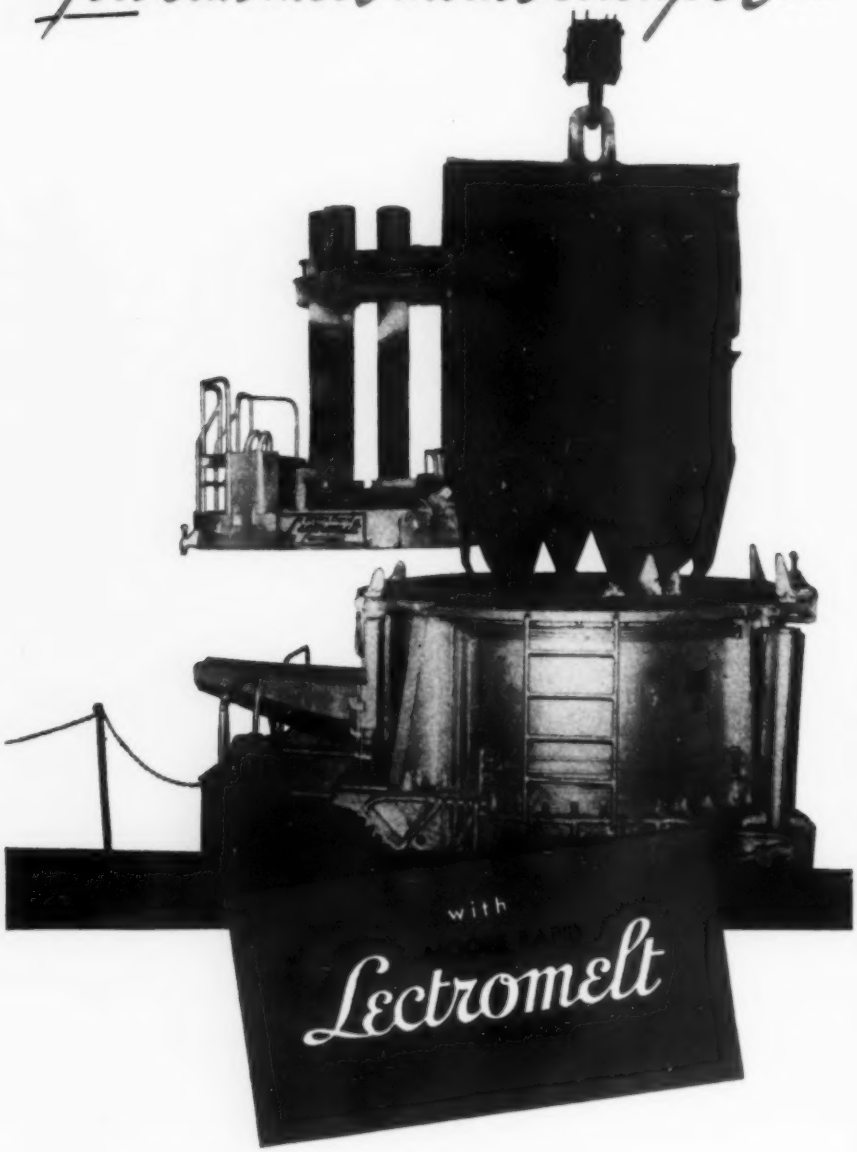

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Mg-Zr Alloys

(Continued from p. 116)

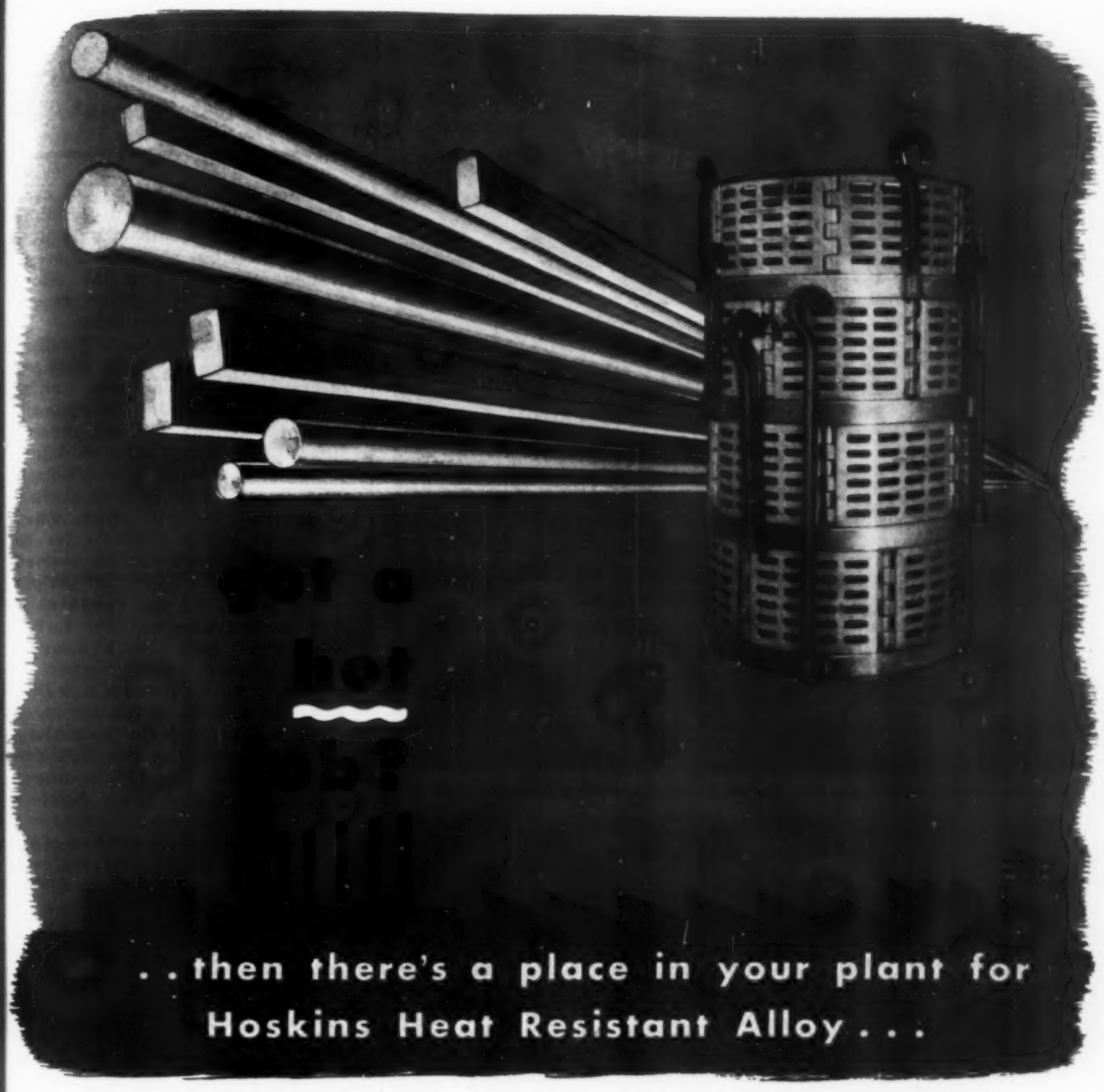
The zinc content of this alloy can be reduced if greater values of elongation are required. Thus, alloy Z3Z, containing 3.0% Zn, 0.7% Zr, will have a proof stress (as cast) of 13,500 to 15,500 psi., and an ultimate of 33,500 to 35,000 psi., elongation in 2 in. of 30%.

A second type of casting alloy, M.C.Z., containing 3.0% rare earths, 0.7% zirconium, balance magnesium, has been developed for high temperature applications. The creep resistance of this alloy is enormously greater than that of magnesium-aluminum alloys and comparable to that of aluminum-base alloys used for this purpose. M.C.Z. has the further advantage that it shows practically no microporosity and may, therefore, be used for castings requiring pressure tightness where high strength is not a primary consideration.

In the wrought form, zirconium-zinc-magnesium alloys not only offer comparably improved properties but they enjoy an ease of fabrication not known to other magnesium-base alloys. For example, a magnesium-zinc-zirconium ingot 70x20x20 in. can be hot rolled in a steel mill using the customary high speeds and heavy reductions. Similarly, because of their excellent hot-working properties, these alloys can be extruded over a wide temperature range up to speeds as high as 100 ft. per min. The most difficult sections can be extruded at 40 ft. per min. without fear of cracking. The best properties are obtained by extruding at a modest speed at low temperatures, whereby a grain size less than 0.003 mm. is obtained.

These alloys can be forged either by hydraulic pressure or impact. They are the only high-strength magnesium alloys known to the author that can withstand forging under drop hammers without "nursing". Their high working temperature of 500° C. (930° F.) makes possible very heavy deformations in a single heat.

Minimum properties in proposed specifications for rolled alloys (1.0 to 5.0% Zn, 0.5 to 1.0% Zr, up to 4.0% Cd) are 31,000 psi. proof stress, 45,000 psi. ultimate tensile strength and 12% elongation in 2 in. Similar properties have been proposed for extrusions or forgings.



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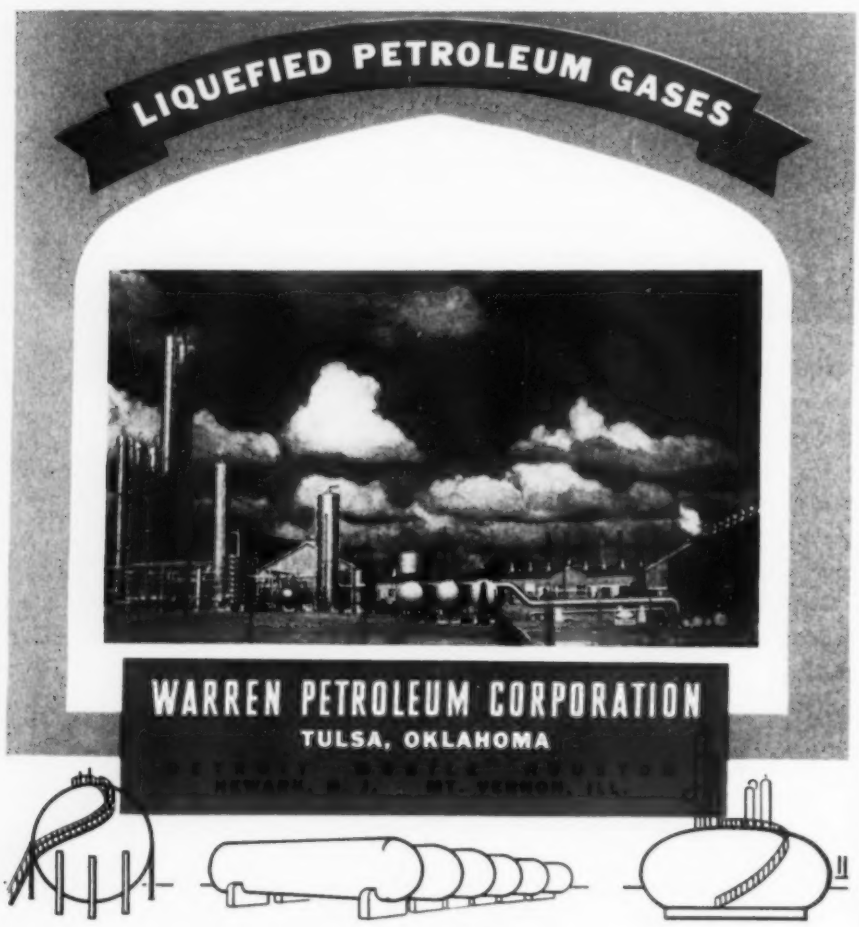

Surface of Annealed 70:30 Brass*

BRIGHT ANNEALING of cartridge brass is rendered difficult not only by ordinary oxidation of the metal but also by the evaporation of zinc from the alloy, which leaves the surface rough, etched and coppery in color.

Experiments show that heating cartridge brass in an atmosphere of cracked ammonia under various pressures will inhibit the evaporation of zinc but will not prevent surface oxidation. Such oxidation is due to the presence of dissolved gases in the brass. In these studies, brass strip 0.022 in. thick, when heated at 400° C. (750° F.) for 30 min. under a high vacuum, evolved a little less than 0.25 cc. of gas per cc. of metal, the gas containing 60% carbon dioxide, 28% carbon monoxide, and 12% hydrogen. When heated under vacuum at 600° C. (1100° F.) for 30 min., a little less than 0.50 cc. of gas per cc. of metal was evolved, the gas containing 54% carbon dioxide, 28% carbon monoxide, and 16% hydrogen. It was found that these dissolved gases must be concentrated near the surface, since only 0.12 cc. of gas per cc. of metal was evolved from the metal when heated at 600° C. (1100° F.) for 30 min. if 0.004 in. of metal was ground from both surfaces of the strip; in this case the evolved gas contained only 16% of carbon dioxide and carbon monoxide each but 66% hydrogen.

Vacuum annealing, while it drew off oxidizing gases and prevented ordinary oxidation, at the same time permitted rapid evaporation of the zinc from the brass.

Using these facts, Mr. Jenkins developed a two-stage cycle for bright annealing brass. The first step was to heat the alloy in vacuum to draw off all oxidizing gases (though some zinc was drawn off also, giving the brass a coppery appearance). The second step was to hold the metal at temperature in a static atmosphere of cracked ammonia to inhibit zinc evaporation, permitting zinc to diffuse from the body of the metal to the surface, restoring its original composition and color. The experimental results *(Cont. on p. 124)*

*Abstracted from "Surface Effects During the Annealing of 70:30 Brass", by I. Jenkins, *Journal* of the Institute of Metals, V. 73, Part II, 1946-1947, p. 641-665.